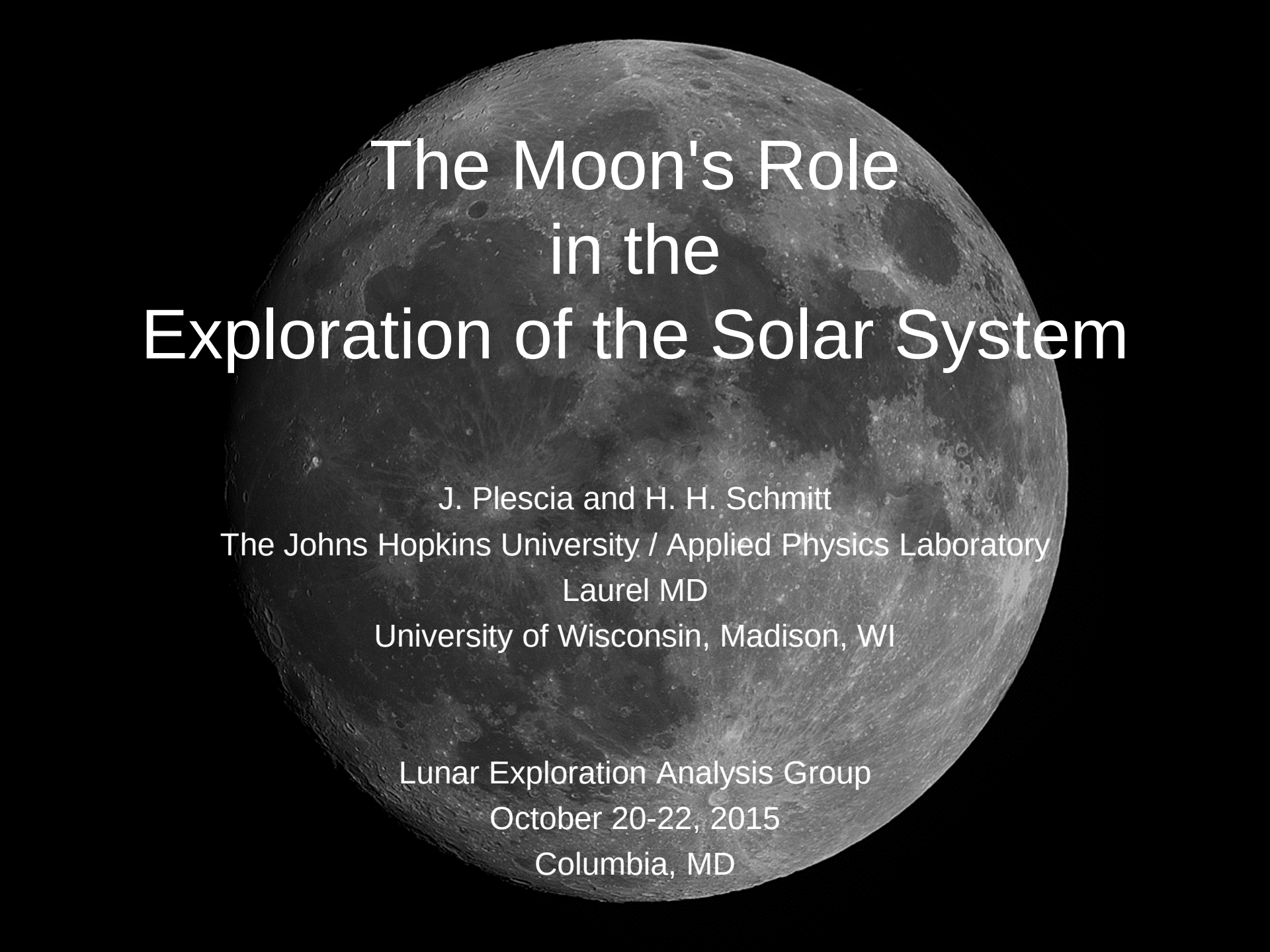
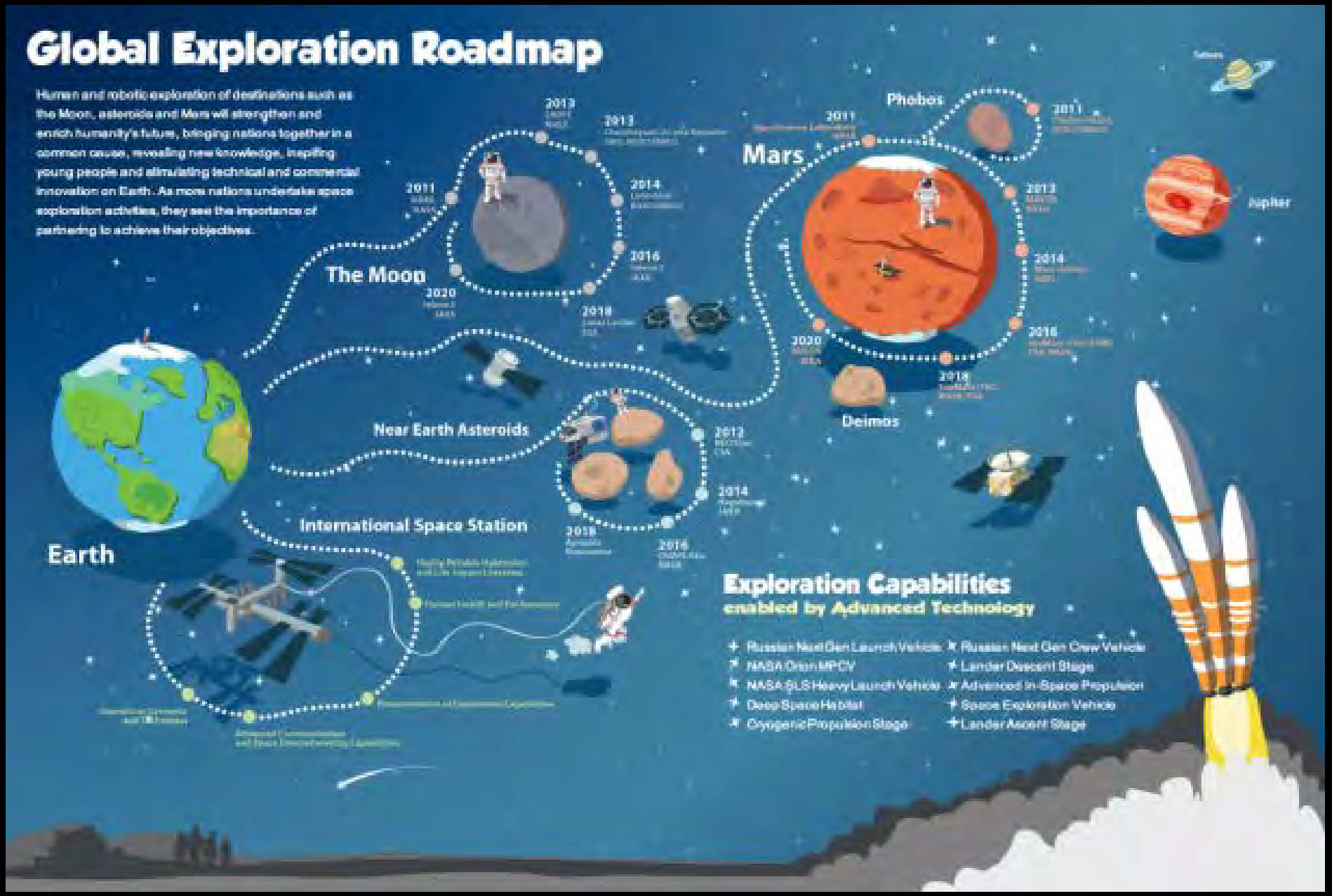


The Moon's Role in the Exploration of the Solar System

J. Plescia and H. H. Schmitt
The Johns Hopkins University / Applied Physics Laboratory
Laurel MD
University of Wisconsin, Madison, WI

Lunar Exploration Analysis Group
October 20-22, 2015
Columbia, MD

EARTH INDEPENDENT
MISSIONS: 2-3 YEARS
RETURN: MONTHS
PROVING GROUND
MISSIONS: 1-12 MONTHS
RETURN: DAYS
EARTH RELIANT
MISSIONS: 6-12 MONTHS
RETURN: HOURS
LANDERS
ORBITERS
SPACE LAUNCH SYSTEM
INTERNATIONAL SPACE STATION
HUBBLE SPACE TELESCOPE
PHOBOS
DEIMOS
MARS TRANSIT HABITAT
ASTEROID REDIRECT MISSION
SOLAR ELECTRIC PROPULSION
ORION CREWED SPACECRAFT
DEEP SPACE HABITAT
COMMERCIAL CARGO AND CREW
SCIENCE
EXPLORATION
TECHNOLOGY


Global Exploration Roadmap
Human and robotic exploration of destinations such as the Moon, asteroids and Mars will strengthen and enrich humanity's future, bringing nations together in a common cause, revealing new knowledge, inspiring young people and stimulating technical and commercial innovation on Earth. As more nations undertake space exploration activities, they see the importance of partnering to achieve their objectives.
The Moon
Near Earth Asteroids
Mars
Phobos
Deimos
Jupiter
Earth
International Space Station
2011
2013
2014
2016
2018
2020
Exploration Capabilities
enabled by Advanced Technology
Russian Next Gen Launch Vehicle
NASA Orion MPCV
NASA SLS Heavy Launch Vehicle
Deep Space Habitat
Cryogenic Propulsion Stage
Russian Next Gen Crew Vehicle
Lander Descent Stage
Advanced In-Space Propulsion
Space Exploration Vehicle
Lander Ascent Stage

Moon's Role

- Science
  - Lunar science – in situ
  - Lunar observatory
  - Laboratory experiments
- Proving Ground - Test bed
  - Technology validation
  - Operations demonstration
- Resources
  - Fuel
  - Life support

- Public Engagement
  - Excitement
  - Tangible goals
  - Visibility
- Commercial Opportunities
- National Security

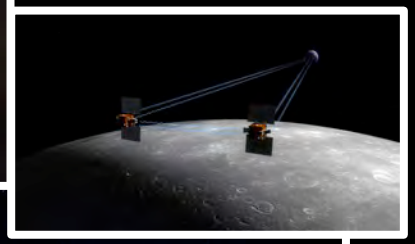
- *Premise: Continued program of solar system exploration with humans and a presence in cislunar space ± Mars.*

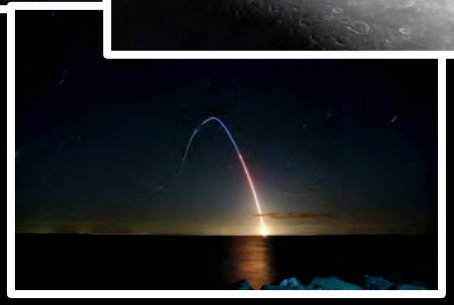
Lunar Science – Recent Missions

LRO/LCROSS

ARTEMIS

GRAIL





LADEE

Chandrayaan

Kaguya

Chang’e 1 & 2 & 3

SMART 1

Lunar Science - Questions

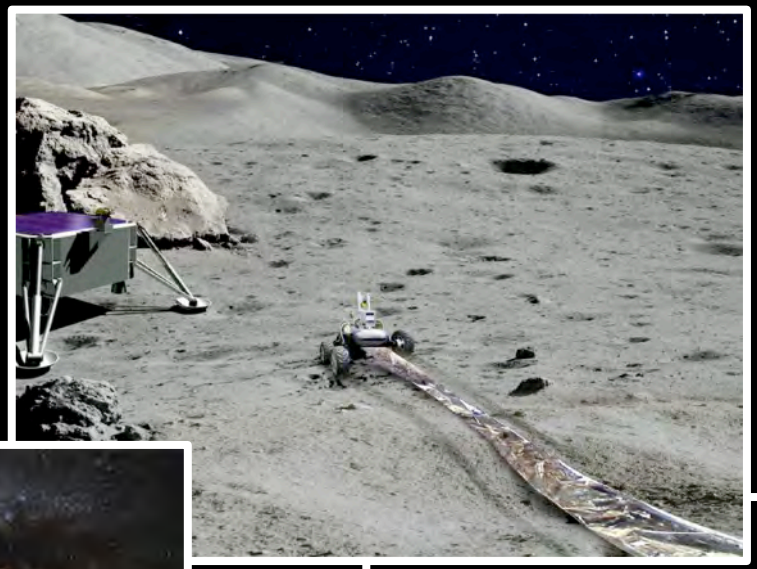
Lunar Exploration Analysis Group (LEAG)

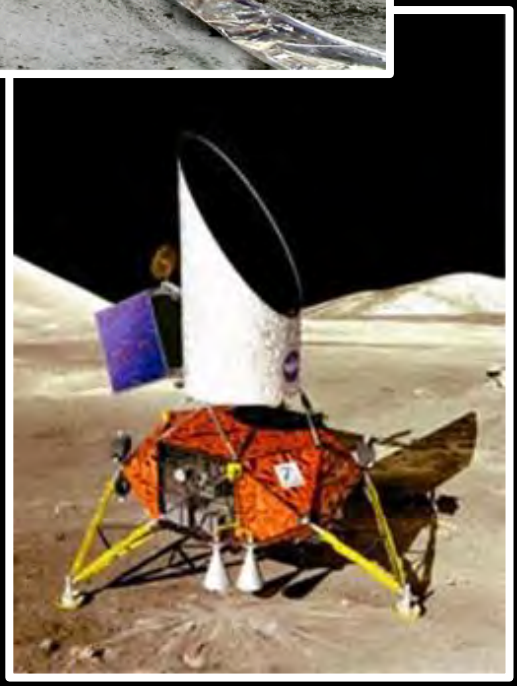
- Understand the environmental impacts of lunar exploration.
- Development and implementation of sample return technologies and protocols.
- Characterize the environment and processes in lunar polar regions.
- Understand the dynamical evolution and space weathering of the regolith.
- Understand lunar differentiation.
- Understand volcanic processes.
- Understand the impact process.
- Determine the stratigraphy, structure, and geological history of the Moon.
- Understand formation of the Earth-Moon system.
- Understand the impact history of the Inner Solar System as recorded on the Moon.
- Regolith as a recorder of extra-lunar processes.

Scientific Context for Exploration of the Moon: Final Report

- Bombardment history of the inner solar system uniquely revealed on the Moon.
- Structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated body.
- Key planetary processes are manifested in diversity of lunar crustal rocks.
- The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history.
- Lunar volcanism provides a window into the thermal and compositional evolution of the Moon.
- The Moon is an accessible laboratory for studying the impact process on planetary scales.
- The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies.
- Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state.

Lunar Science - Observatories





Moon – Proving Ground - Test Bed

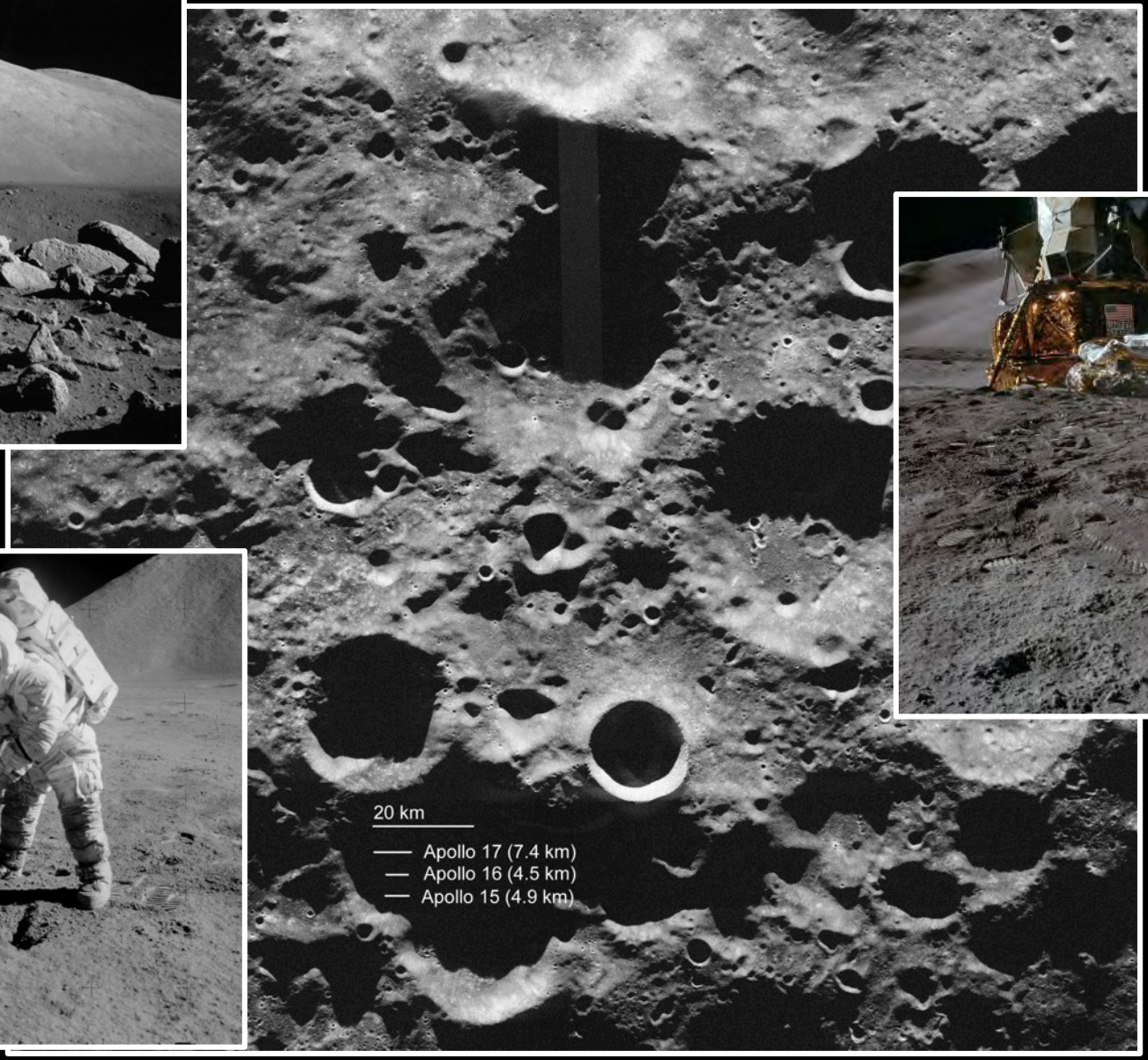
- Surface or Cislunar Space

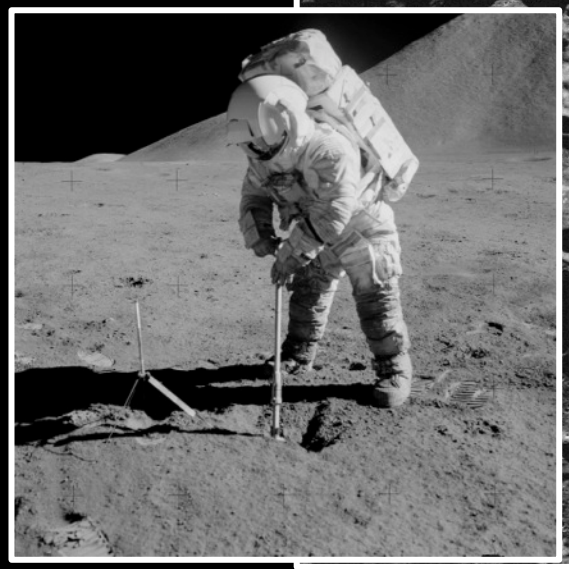
- Deep space environment
- Deep space radiation environment (at least part time)

- Low gravity (1.622 vs. 3.771 m/sec/sec)
- Fine-grained, granular surface material (magnetic)
- Proximity – communication, safety, risk reduction

NASA - The Proving Ground

Et Al. – The Proving Ground

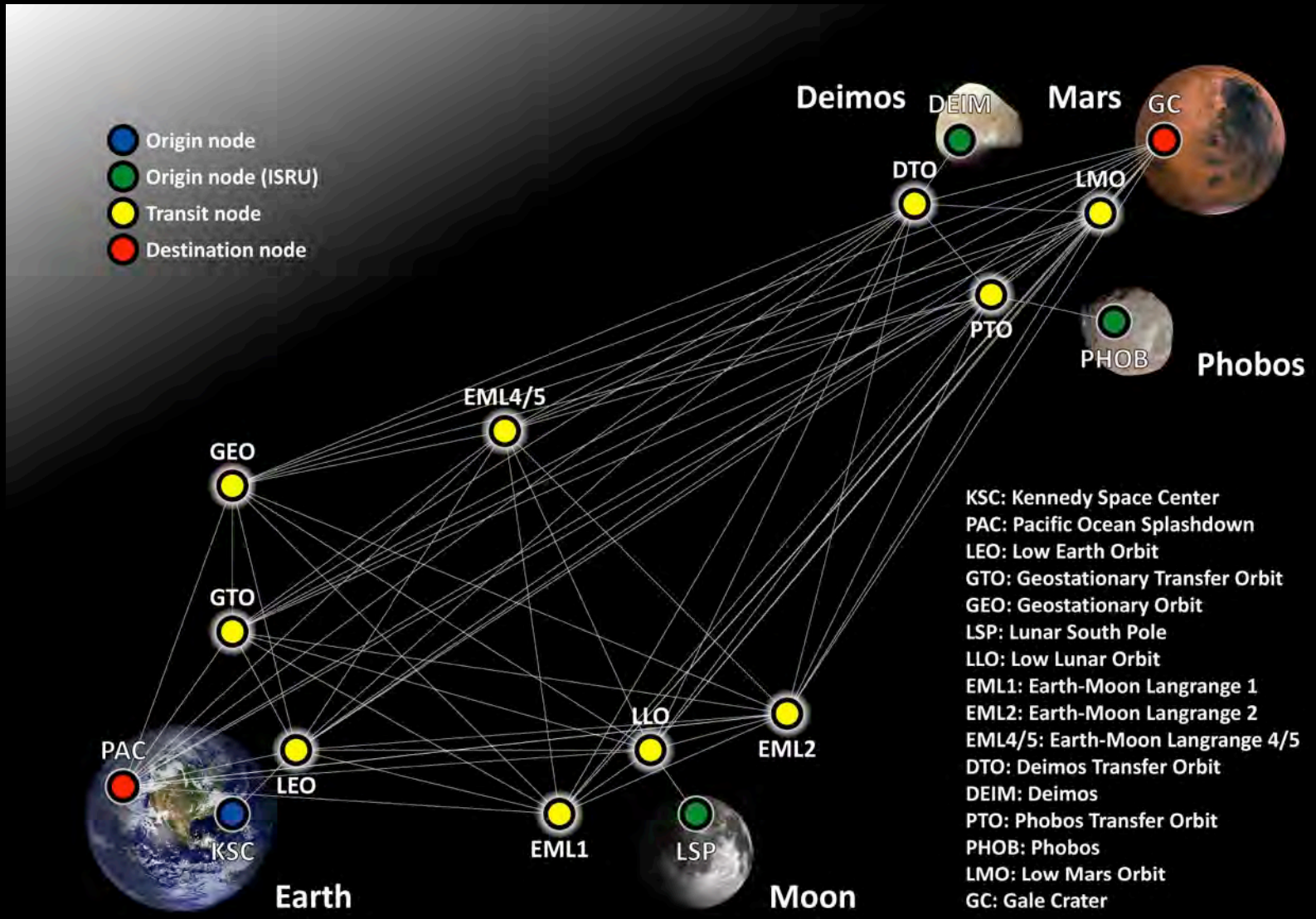




ISRU

Locate Resrouces
Process
Storage
Transfer

Lunar Resources



Ishimatsu et al., 2013, AIAA SPACE 2013

Lunar Resources

Oxygen and hydrogen are valuable commodities
- Oxygen - human consumption and oxidizer
- Hydrogen (H_2O) - life support, radiation shielding, propellant, fuel cells

Present on the Moon - small amounts (H_2) or tightly bound to metals (O)
- Significant amounts of time and energy to extract, purify, and store
- Heat regolith to 700˚ C to drive off solar wind H_2, higher temperatures to crack oxygen
- Movement and handling of large amounts of regolith

Lunar polar ice is a concentrated, easily usable form of hydrogen and oxygen
- Remove water by heating to 100˚ C
- Might be possible to extract *in situ*
- Electrolyze water into component H_2 and O_2, liquefy and store
- Relatively simple processing compared to solid-gas or liquid-gas reactions

Lunar Resources

Define the resource
Understand how to extract it
Calculated the costs
Make a decision

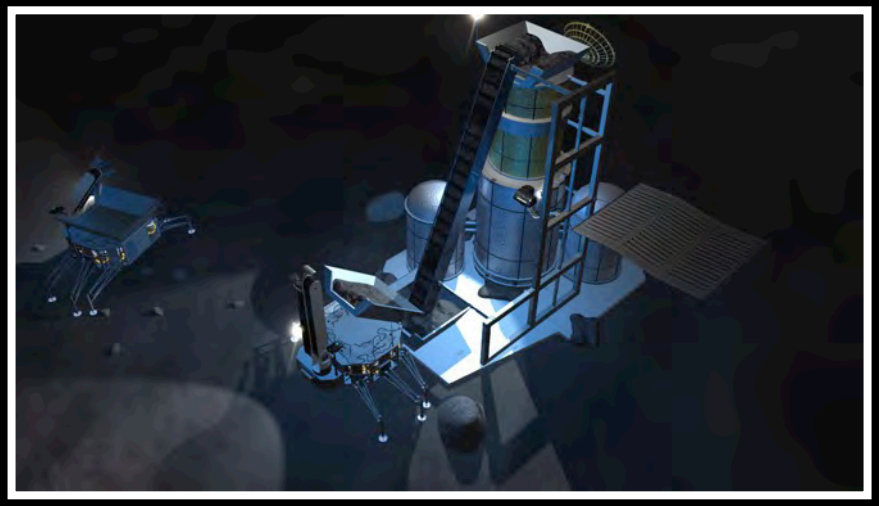
Drives the outpost site selection process
- Distance to ore
- Power for production
- Transport of resource

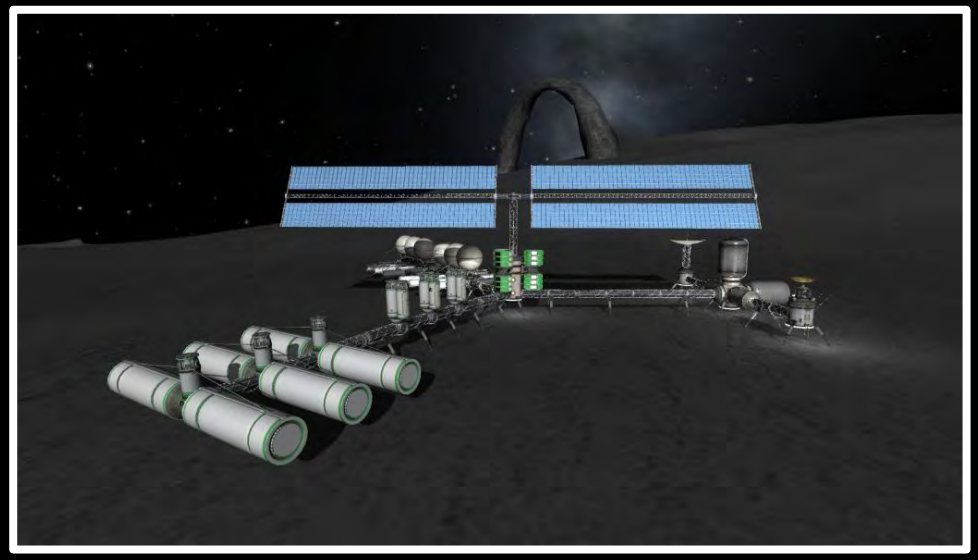
Lunar Resources

Demonstrate

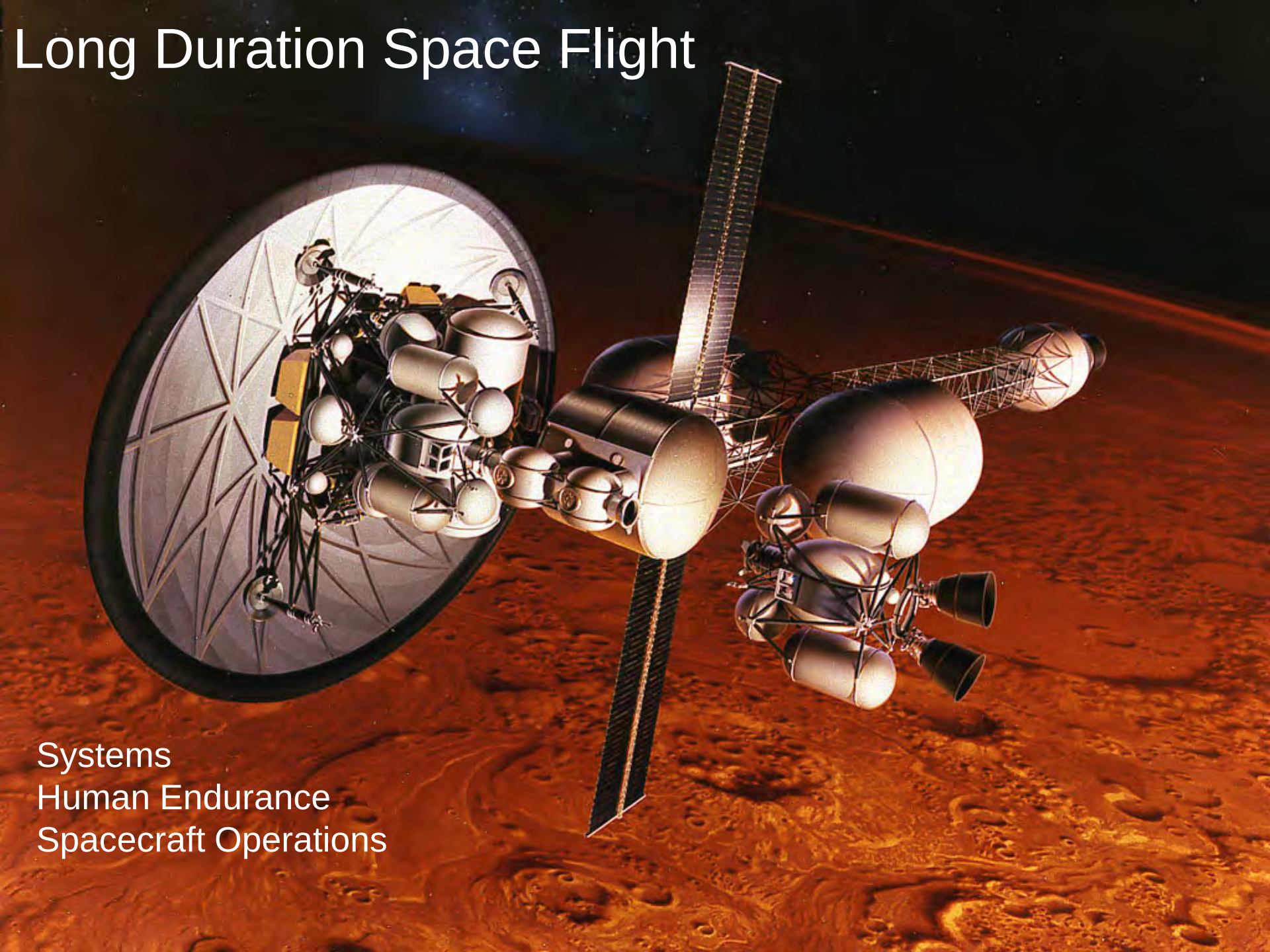
- Excavation and transport
- Recovery of volatiles
- Cryogenic storage and transfer

Requires advanced power, mobility, large landed payload capacity





Long Duration Space Flight

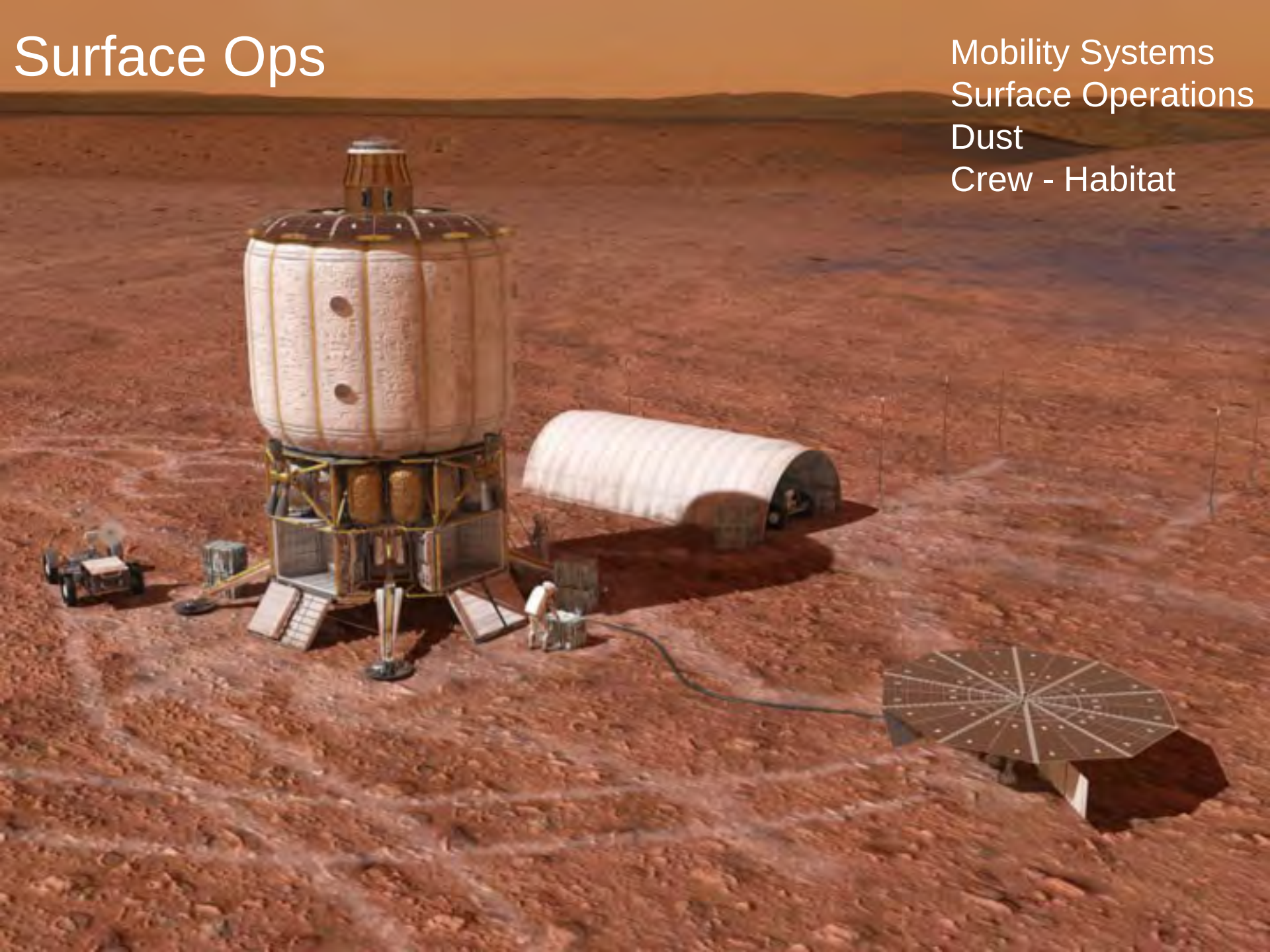


Systems
Human Endurance
Spacecraft Operations

Long Duration Space Flight

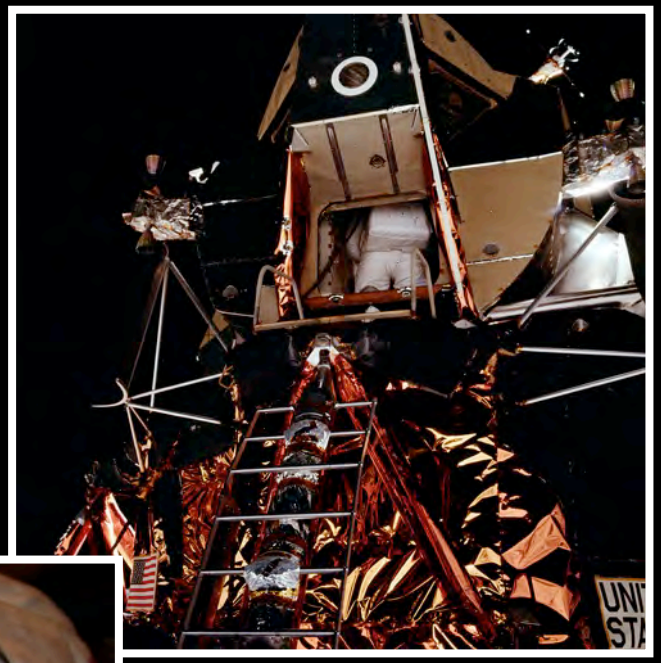
Surface Ops

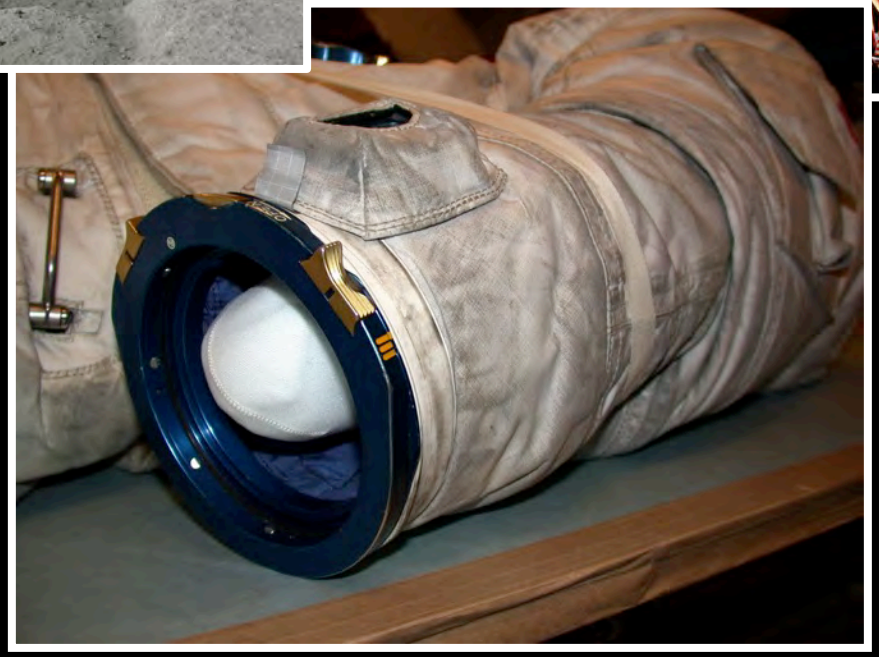
Mobility Systems
Surface Operations
Dust
Crew - Habitat

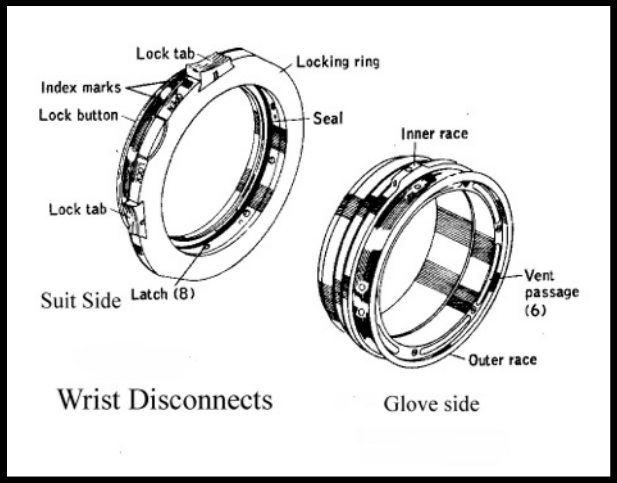


Dust

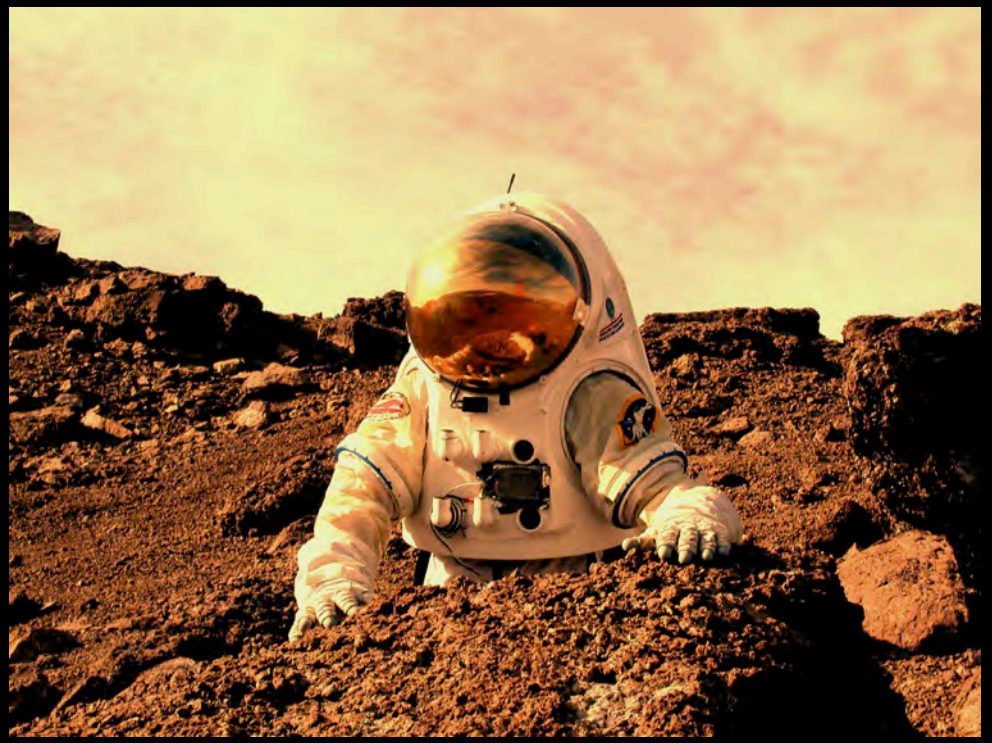
Dust






Lock tab
Locking ring
Index marks
Lock button
Seal
Inner race
Lock tab
Vent passage (6)
Suit Side
Latch (8)
Outer race
Wrist Disconnects
Glove side

Humans and Robots



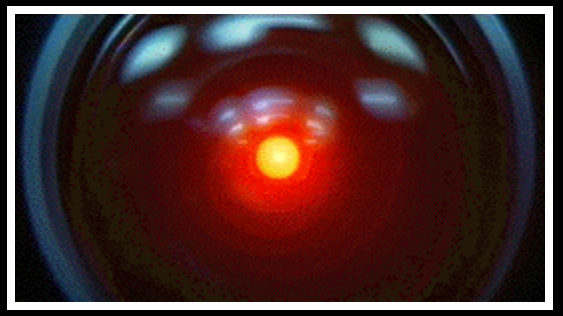
Humans and Robots - Robots

Pro

- Expendable – risky situations
- Excellent at boring, repetitious tasks – listening to me
- Environmentally robust – operate in extreme environments
- Continuous to near-continuous duty cycle – don't sleep

Con

- Limited intellectual capability – they only do what they are asked, usually
- Slow - data rate, power constrained
- Limited payload
- Expensive



I'm sorry Clive, I'm afraid I can't do that.

Humans and Robots - Humans

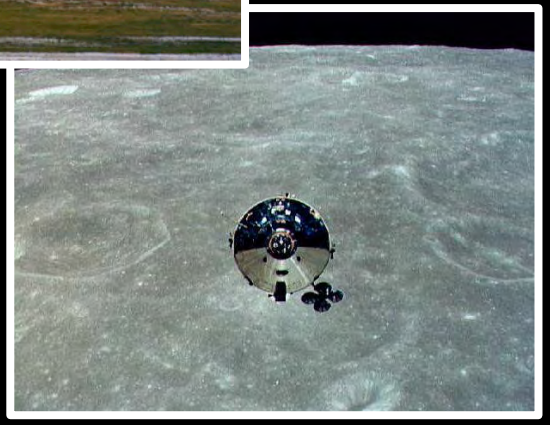
Pro

- Intellectually flexible – orange soil at Apollo 17
- Adaptable to different situations
- Communicate ideas not just data
- Mechanically flexible – Hubble, ALSEP
- Ability to handle difficult terrain – rock strewn ejecta
- Ability to distinguish critical data from mass of
  of irrelevant information

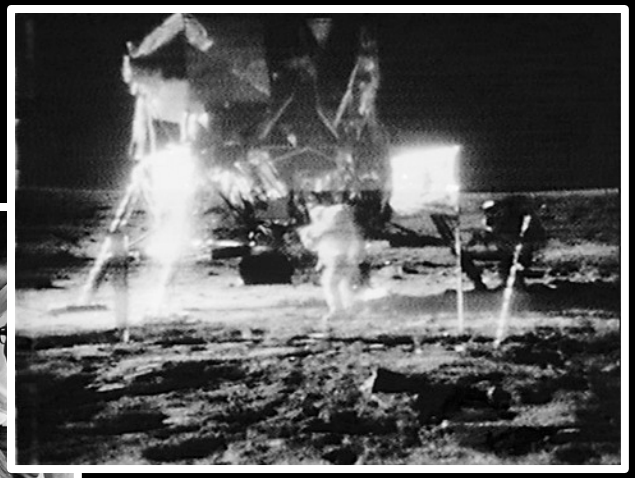
Con

- Require life support
- Need to sleep, eat, and …

Visible Milestones



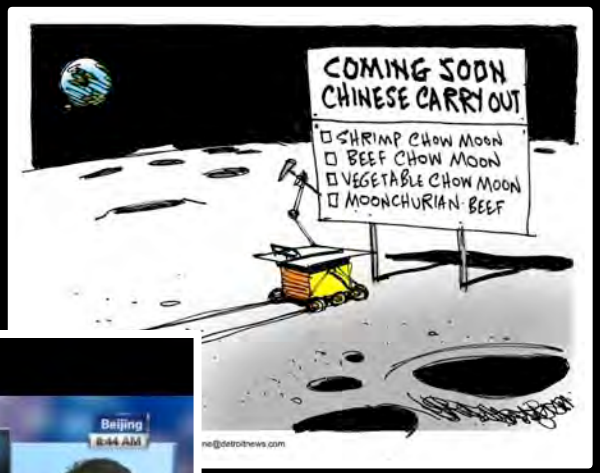
Public Engagement



Inspiration

Inspiration

National Security

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Weird Trip
OF LUNAR
EXPLORATION!