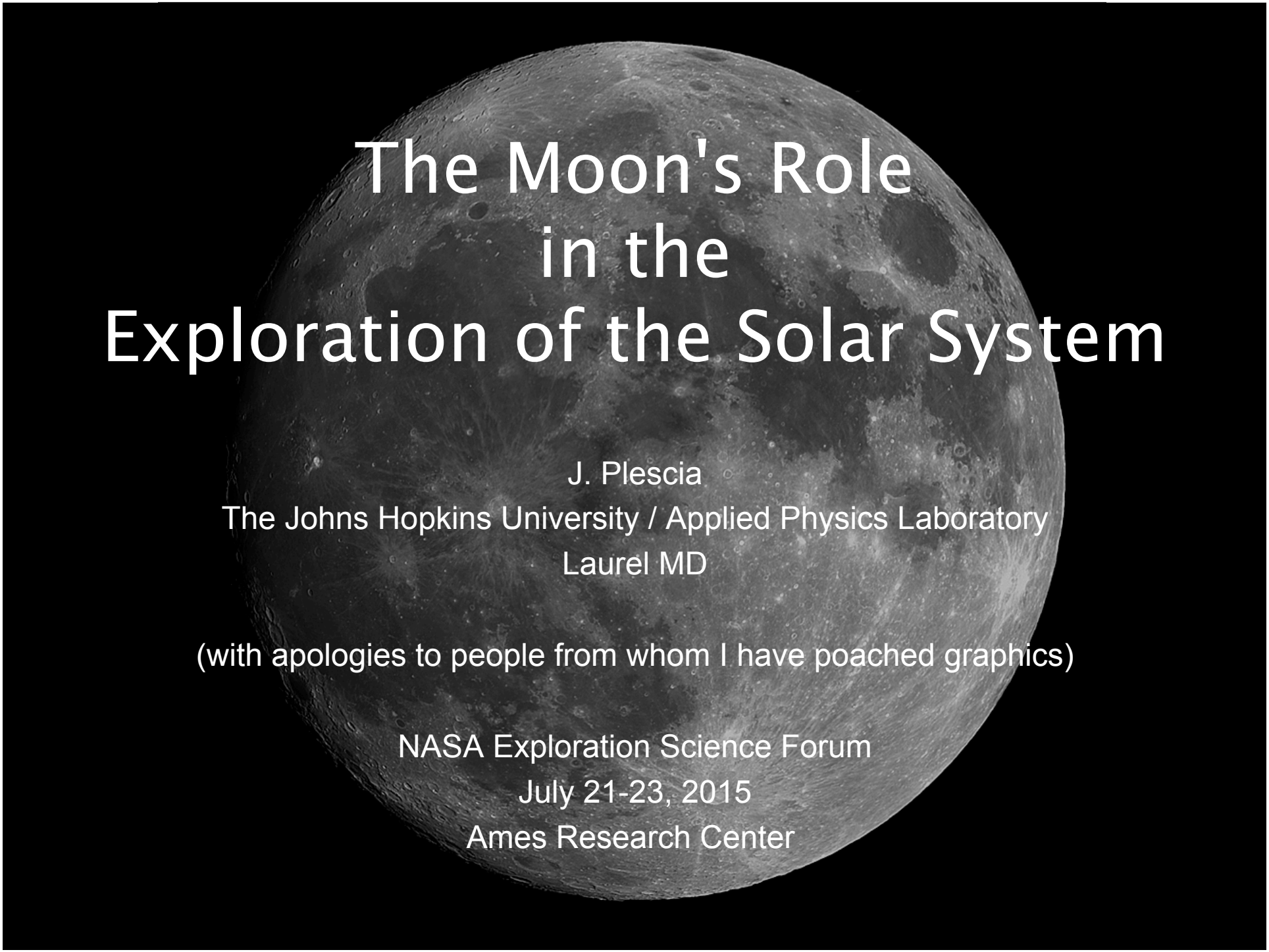


The Moon's Role in the Exploration of the Solar System

J. Plescia
The Johns Hopkins University / Applied Physics Laboratory
Laurel MD

(with apologies to people from whom I have poached graphics)

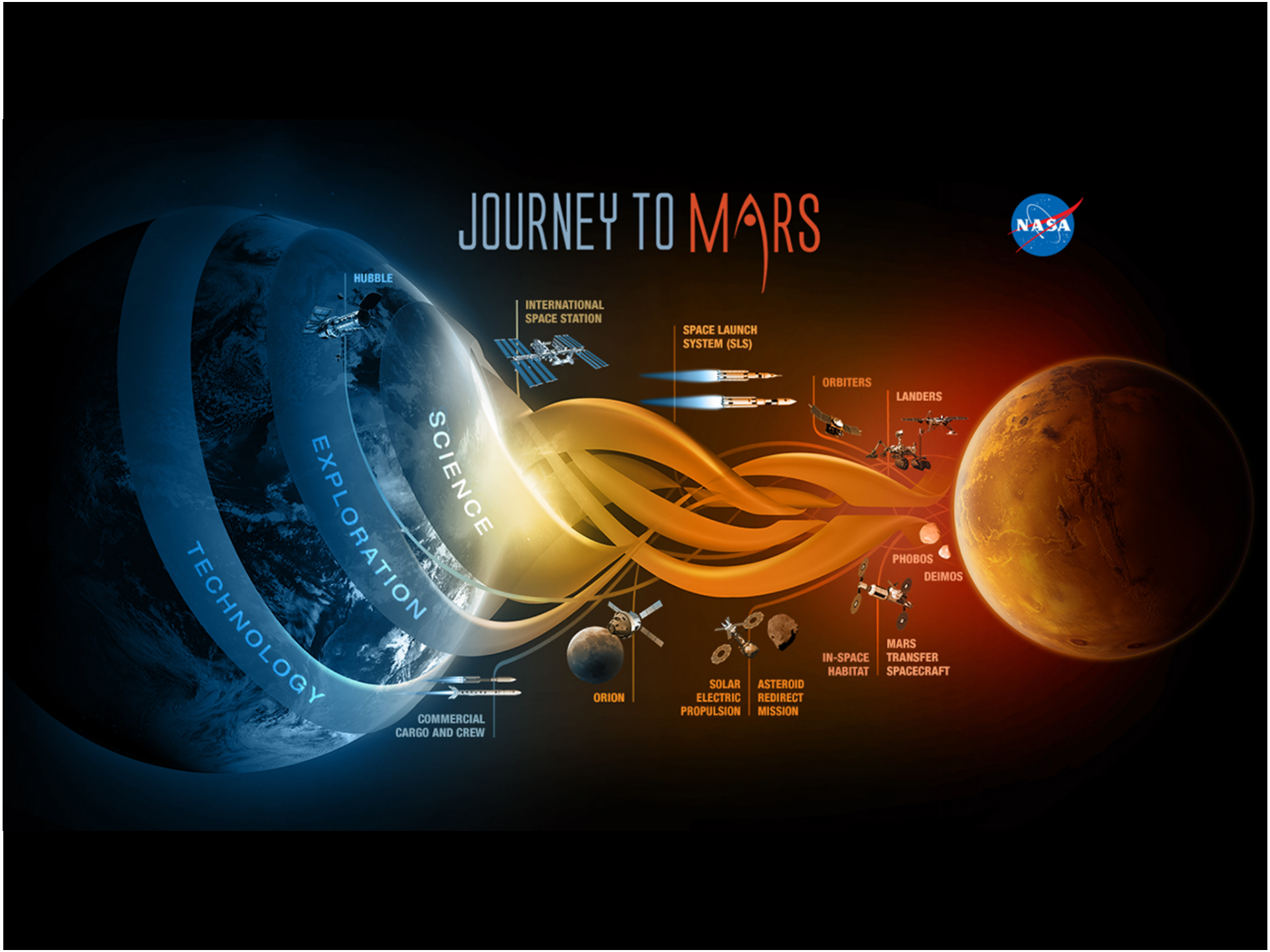
NASA Exploration Science Forum
July 21-23, 2015
Ames Research Center

Moon's Role

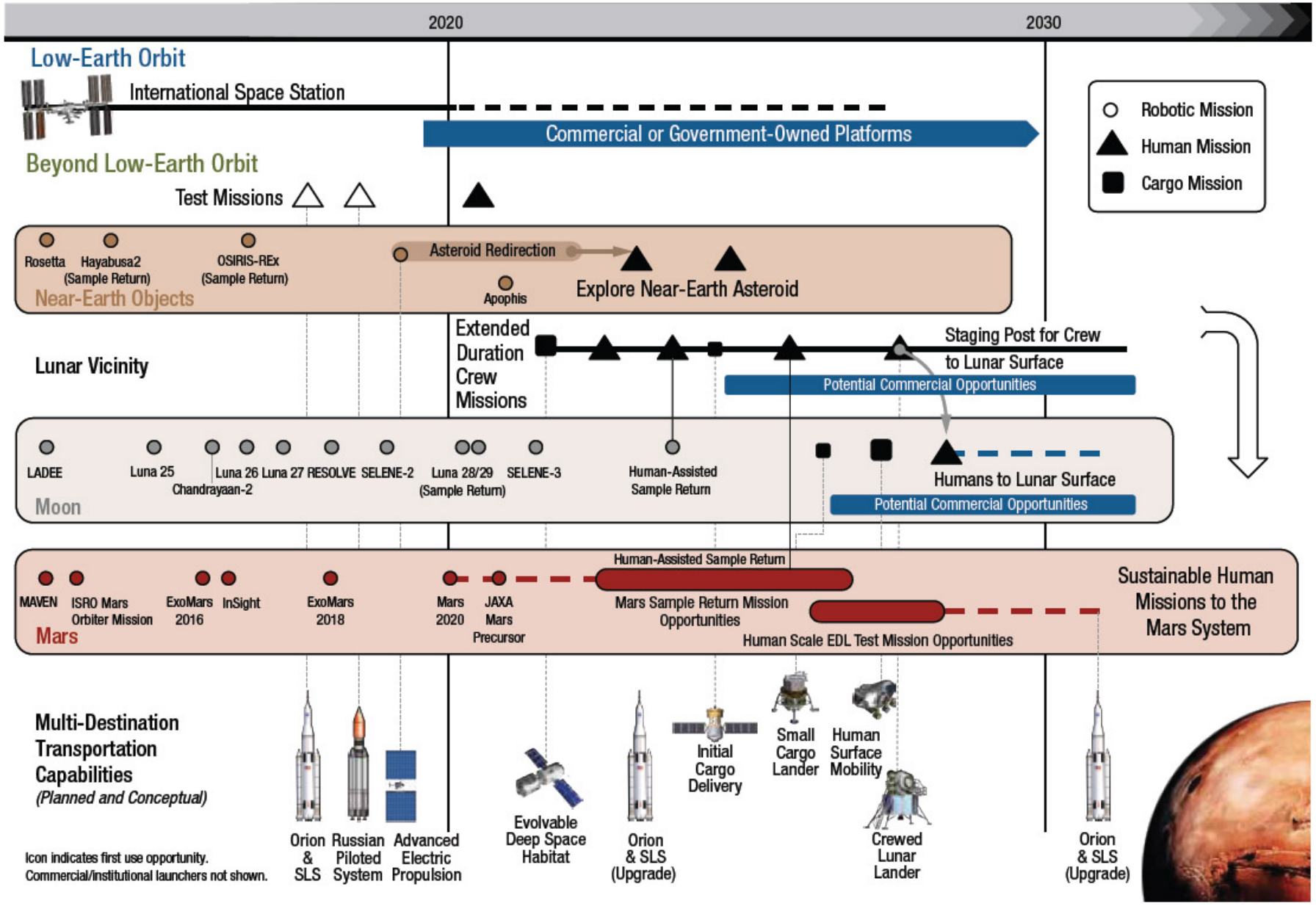
- Science
  - Lunar science – in situ
  - Lunar observatory
  - Laboratory experiments
- Test bed
  - Technology validation
  - Operations demonstration
- Resources
  - Fuel
  - Life support

- 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.*

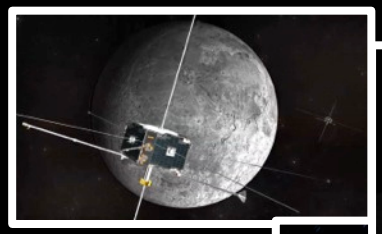

JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
COMMERCIAL CARGO AND CREW
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT

ISECG Mission Scenario



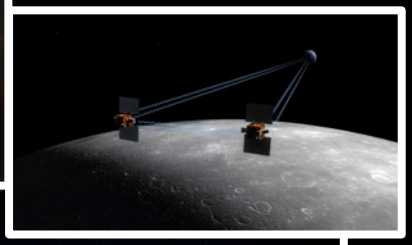
Lunar Science – Recent Missions

LRO/LCROSS



ARTEMIS

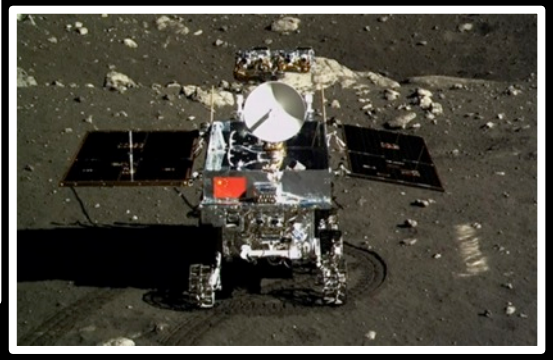
GRAIL



LADEE

Chandrayaan

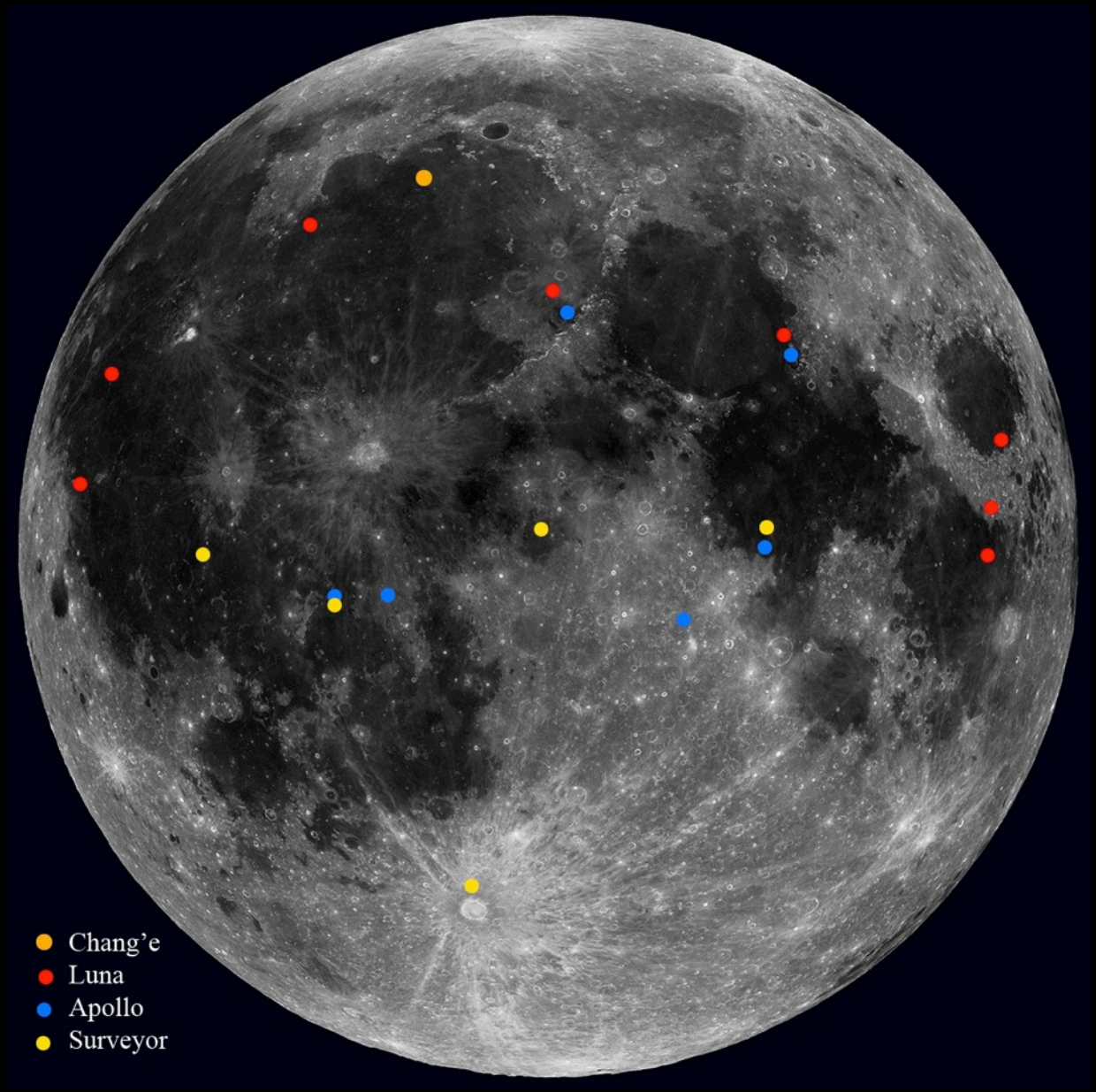
Kaguya



Chang’e 1 & 2 & 3

SMART 1

Lunar Science – Surface Missions



Lunar Science - Questions

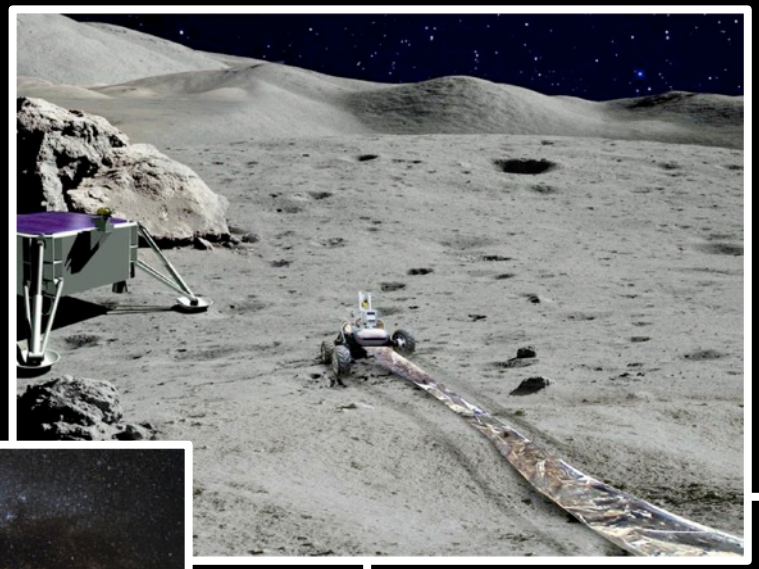
Lunar Exploration Analysis Group (LEAG)

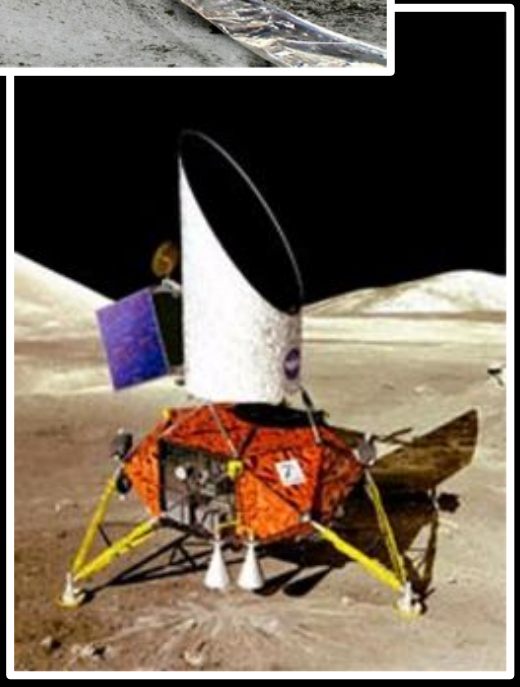
- **Understand the environmental impacts of lunar exploration.**
- **Development and implementation of sample return technologies and protocols.**
- **Characterize the environment and processes in lunar polar regions.**
- **Understand the dynamical evolution and space weathering of the regolith.**
- **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



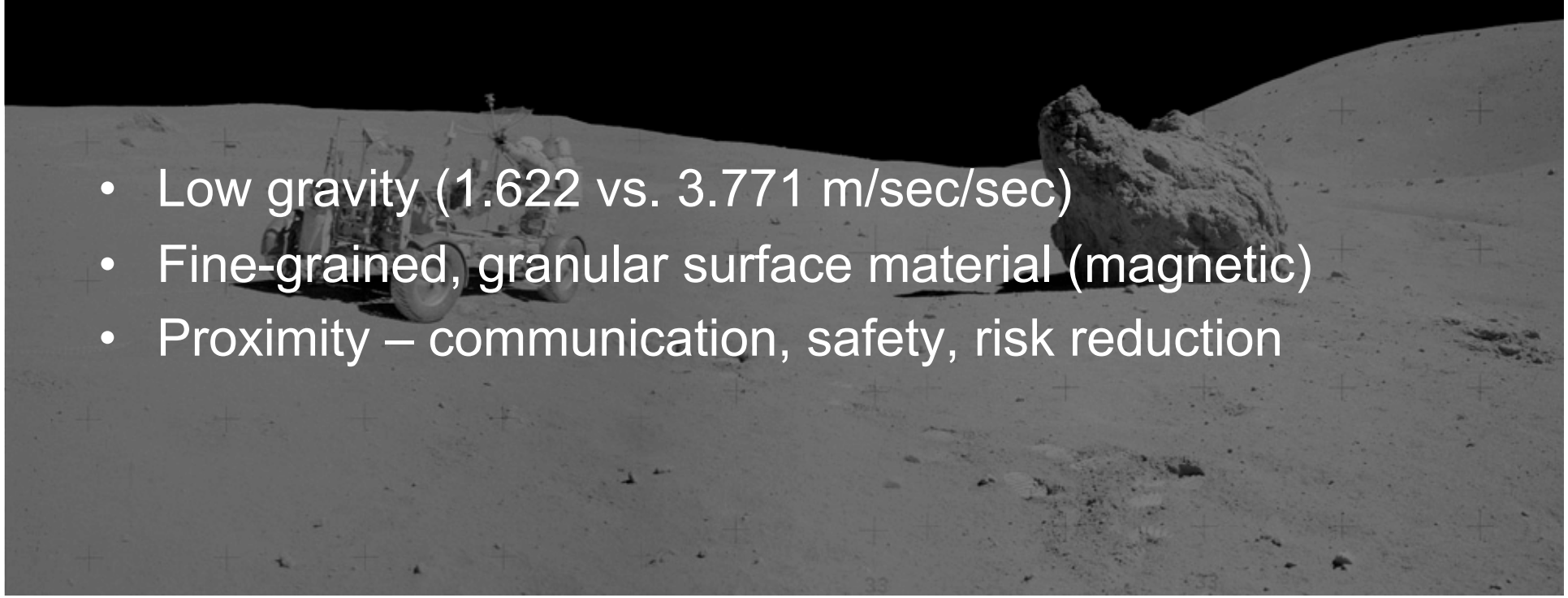


Moon - Test Bed

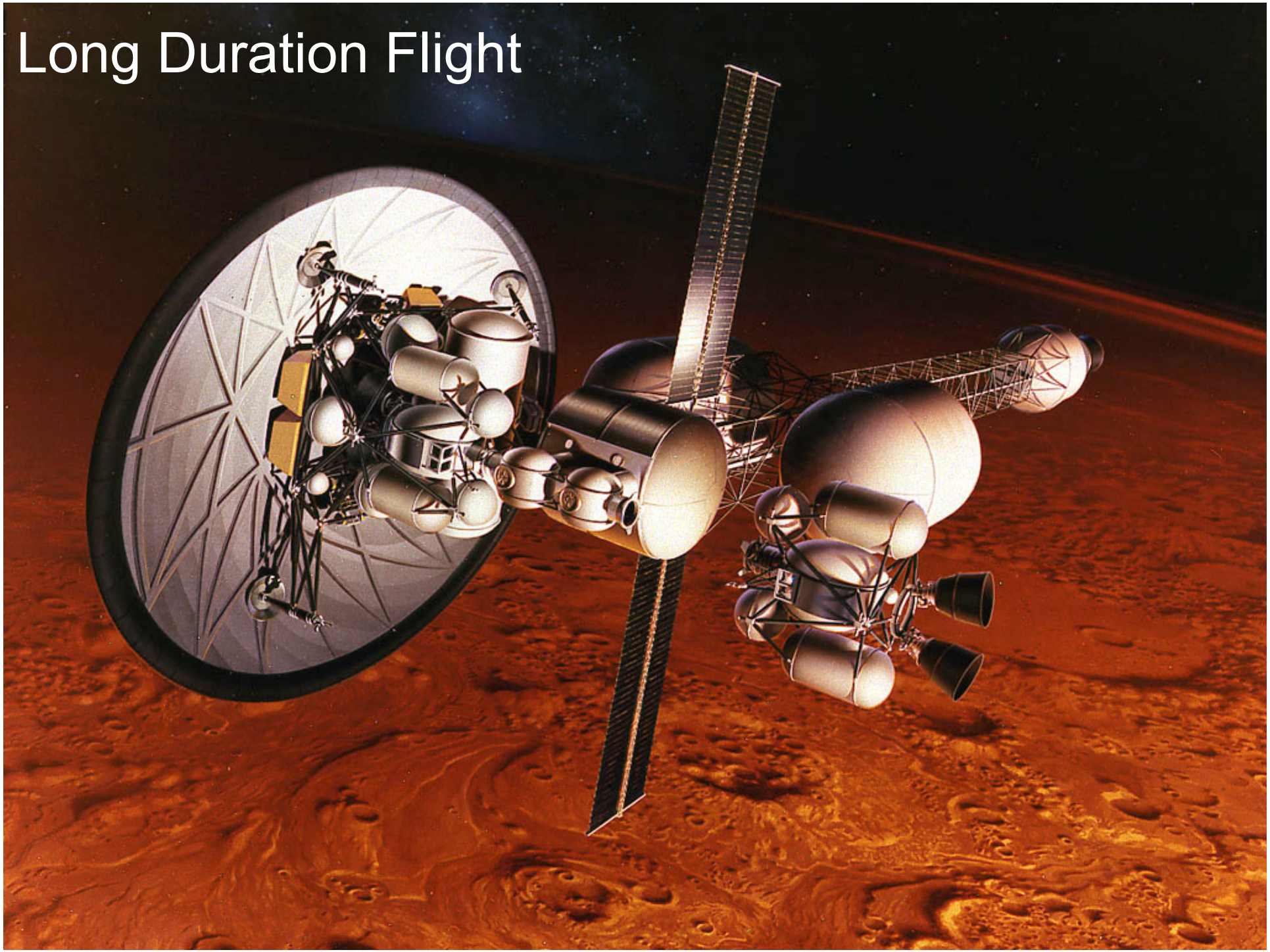
- Surface or Cislunar Space

- 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

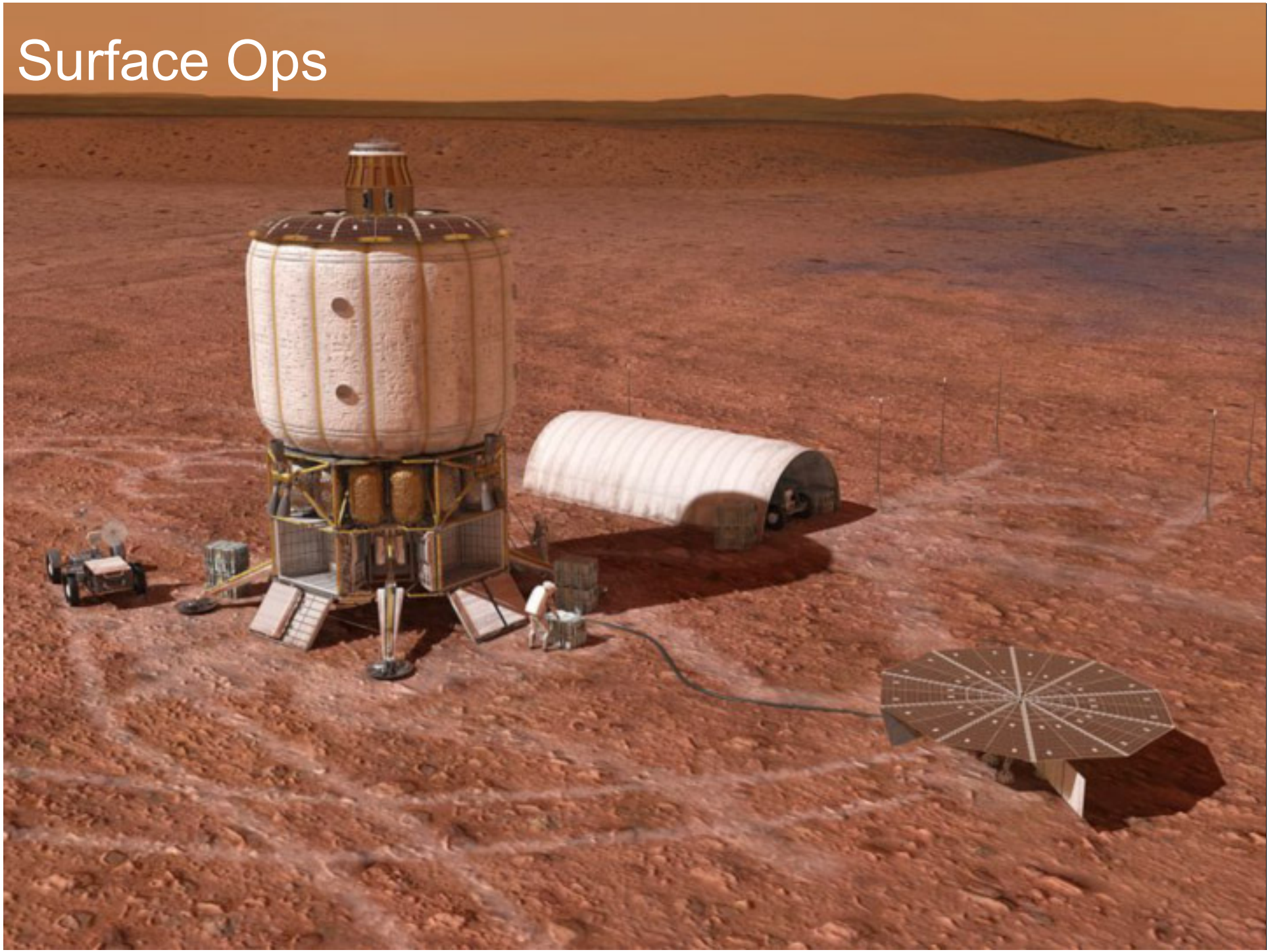


Long Duration Flight

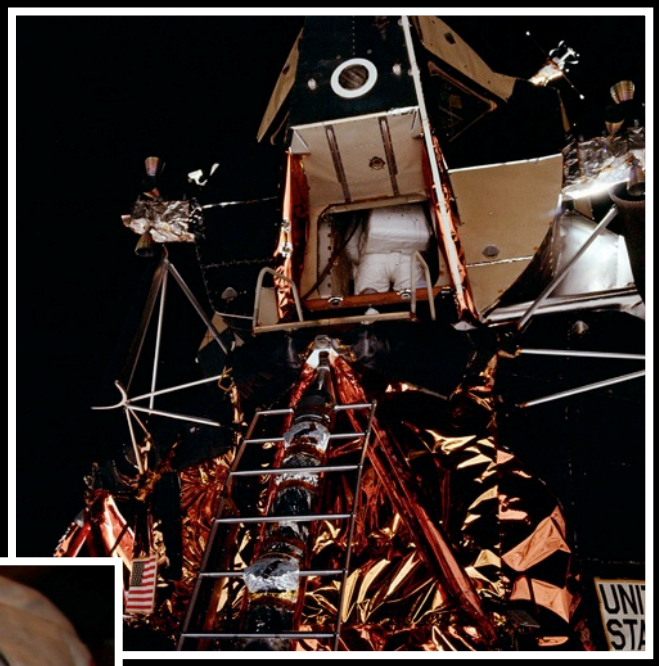


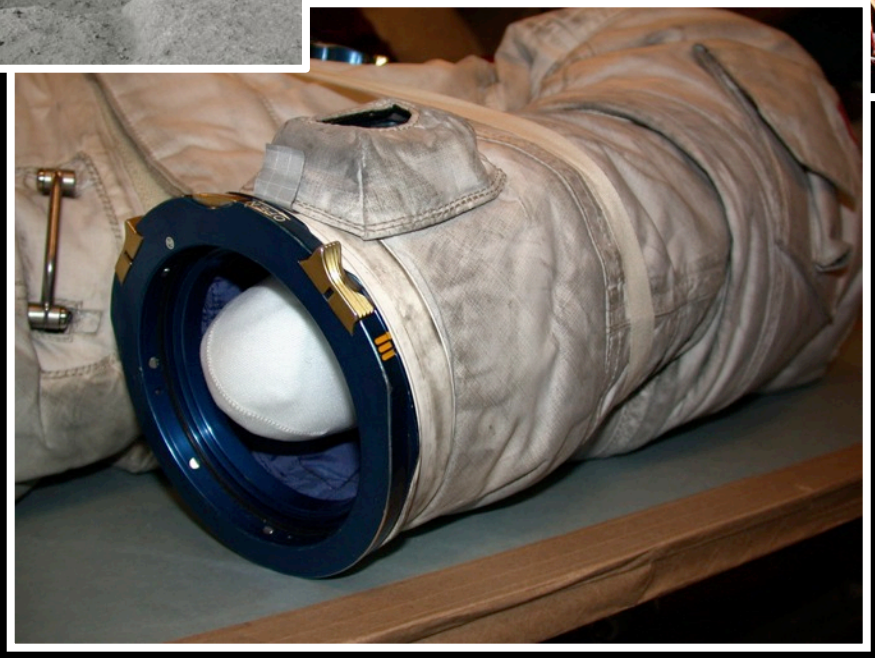
ISRU

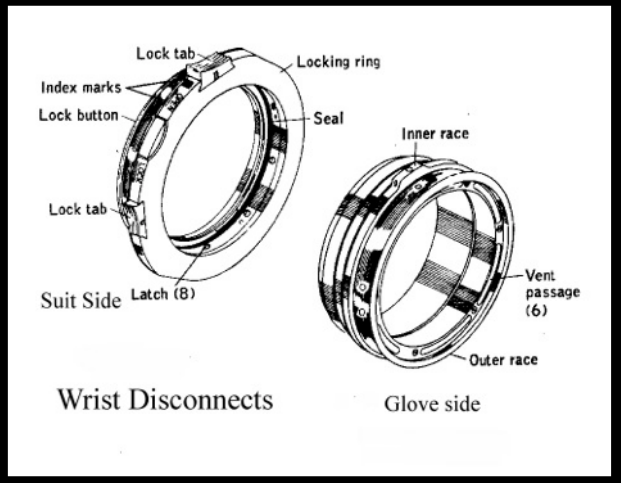
Surface Ops



Evils of Regolith and Dust





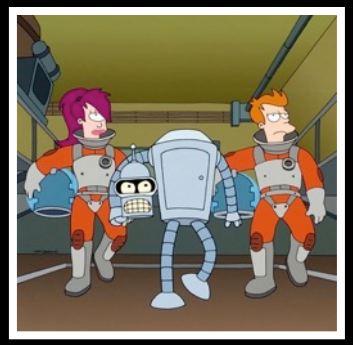


Evils of Regolith and Dust

Understand Interplay Between Humans and Robots

"When does the human become the tool of choice for solar system exploration?"

"How should the ratio of humans to robots change over time to meet that goal?"



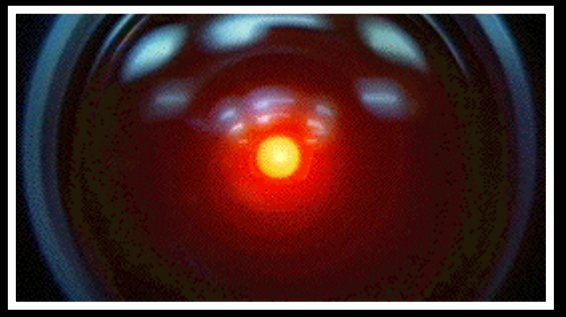
Understand Interplay Between Humans and Robots - Robots

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.

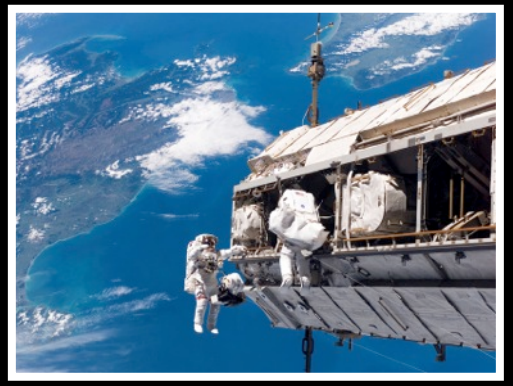
Understand Interplay Between Humans and Robots - Humans

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 …



Lunar Resources

	Apollo 11 soil (mare)	Apollo 16 soil (terrae)
H	20-100 ppm	4-40 ppm
He*	19-80 ppm	3-35 ppm
Ar	1.3-12 ppm	0.7-3 ppm
Xe	0.5-3.8 ppm	0.2-1 ppm
C	100-200 ppm	30-280 ppm
N	20-80 ppm	4-200 ppm
K	1000-1800 ppm	380-1100 ppm
P	480-650 ppm	130-1100 ppm
S	660-1500 ppm	470-640 ppm
F	75-520 ppm	27-105 ppm
Cl	3-40 ppm	12-270 ppm

* $^{4}He/^{3}He$ = ~ 2500

1 m^3 of lunar regolith contains enough hydrogen, carbon, nitrogen, potassium, and other trace elements to make lunch for two – two cheese sandwiches on rye, two colas (flavored with real sugar, although there's enough Cl to sweeten it with Splenda instead), and two large plums.

L. Taylor

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

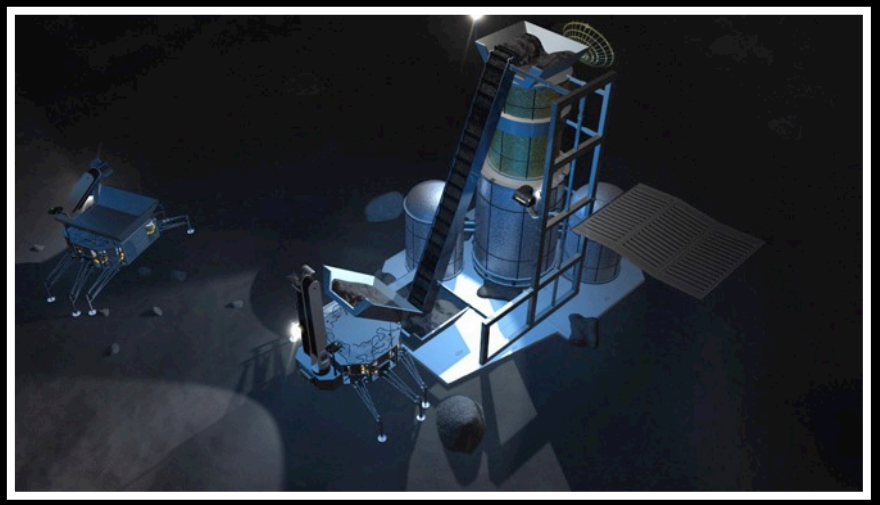
Drives the outpost site selection process
- Distance to ore
- Power for production
- Transport of resource

Lunar Resources - Demonstration

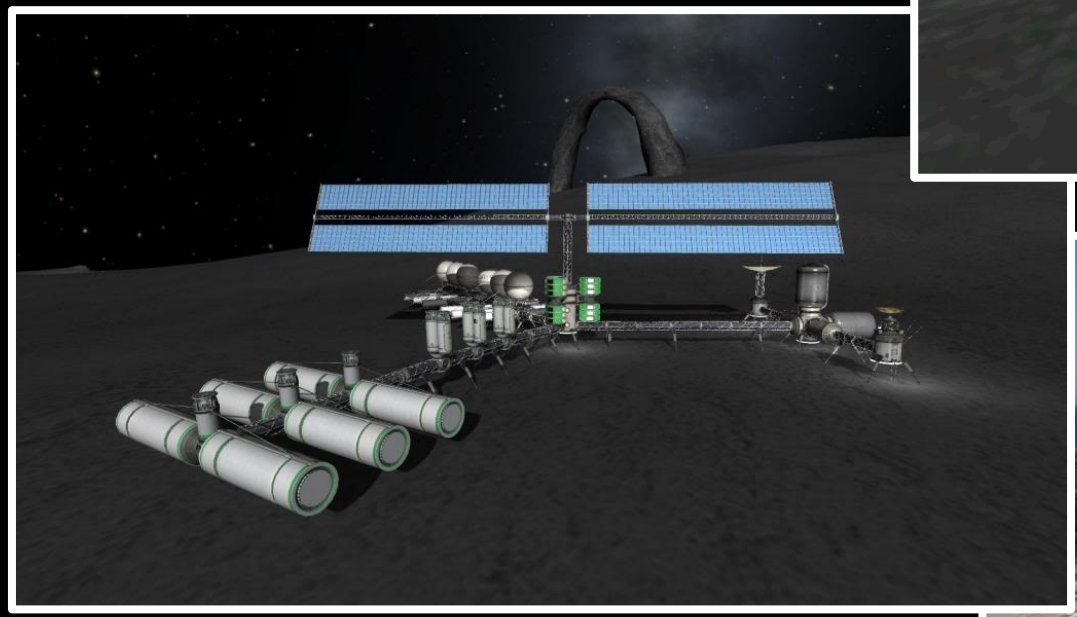
Demonstrate

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

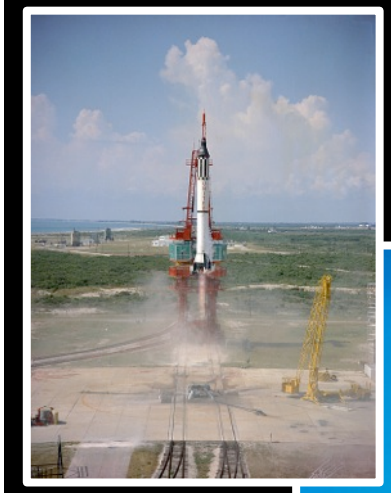
Requires advanced power, mobility, large landed payload capacity

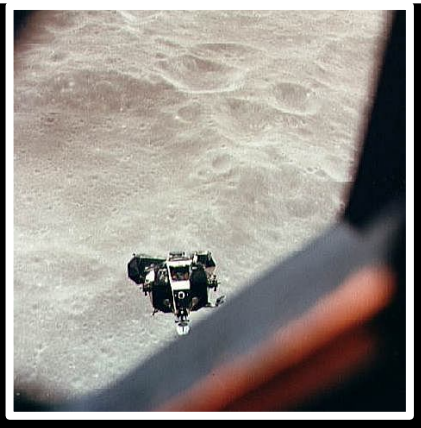


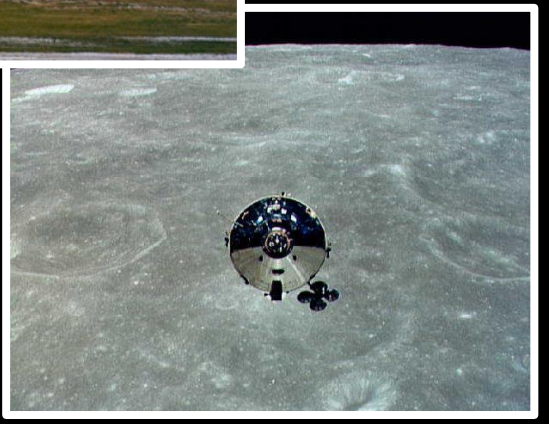
Lunar Resources - Processing, Storage, Use



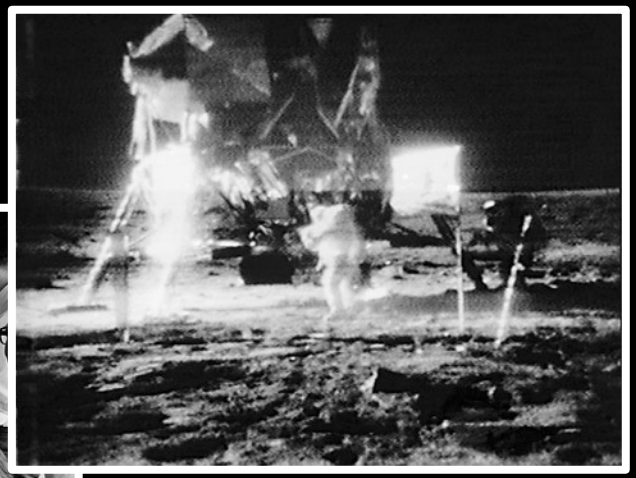
Visible Milestones





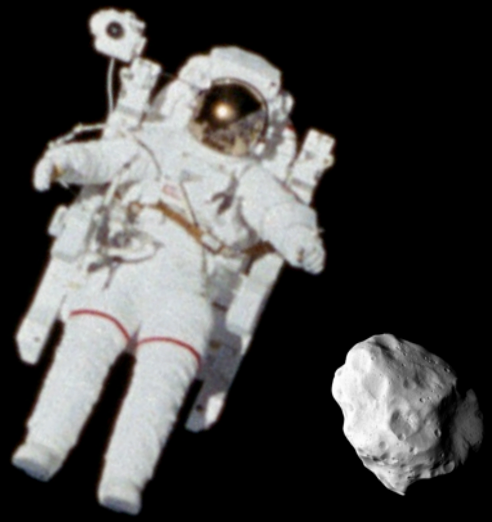


Public Engagement



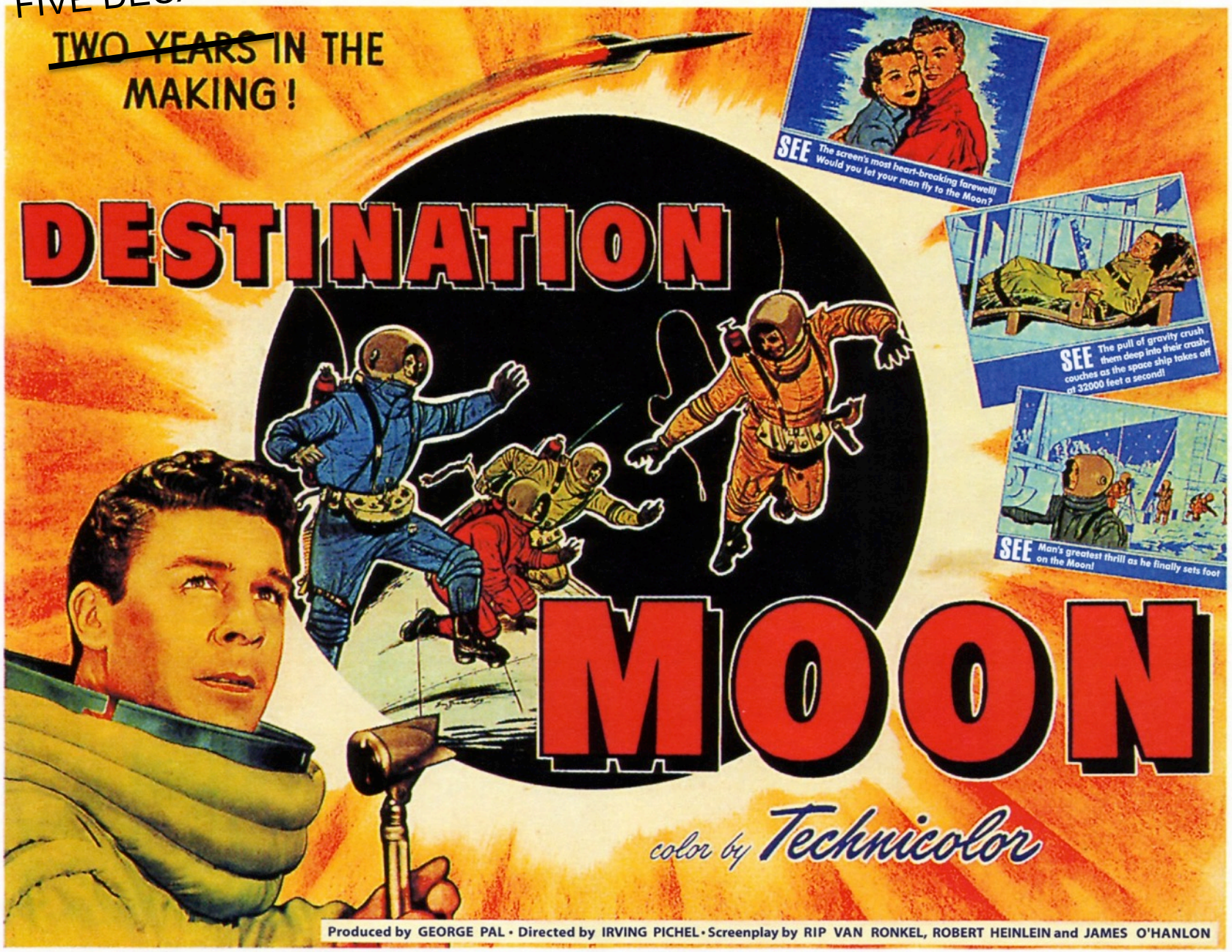
Public Engagement

Public Engagement




MGM PRÉSENTE
PLANETE INTERDITE
"FORBIDDEN PLANET"
EN COULEURS
CINEMASCOPE
WALTER PIDGEON · ANNE FRANCIS
LESLIE NIELSEN
SURPRENANT! VERRASSEND!
VERBODEN PLANEET

FIVE DECADES



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