

# **Scientific Exploration of the Solar System: Humans beyond LEO**

**Clive R. Neal**

University of Notre Dame, USA  
([neal.1@nd.edu](mailto:neal.1@nd.edu))

# **Scientific Exploration of the Solar System: Humans beyond LEO**

**Clive R. Neal**

University of Notre Dame, USA  
([neal.1@nd.edu](mailto:neal.1@nd.edu))

Dedicated to the memory and legacy of Mike Wargo



Science Enables Exploration and  
Exploration Enables Science



# Current Space Policy

President Obama announced his intentions for NASA on April 15, 2010, at a major space policy speech at KSC. He committed to:

- abandoning the Moon
- increasing NASA funding by \$6 billion over five years
- completing the design of a new heavy-lift launch vehicle by 2015 and to begin construction thereafter.

He also predicted a U.S.-crewed orbital Mars mission by the mid-2030s, preceded by an asteroid mission by 2025.



# NASA Funding

YEAR	FUNDING \$ (Millions)	% FEDERAL BUDGET
2010	18,724	0.52
2011	18,448	0.51
2012	17,770	0.50
2013	16,865	0.49
2014	17,647	0.50
2015	18,010	?

**2010-2015 difference = \$-714 million**

**Conclusion:** The funding needed for NASA to achieve the goals of the current space policy is lacking.

# That Jaded Feeling!

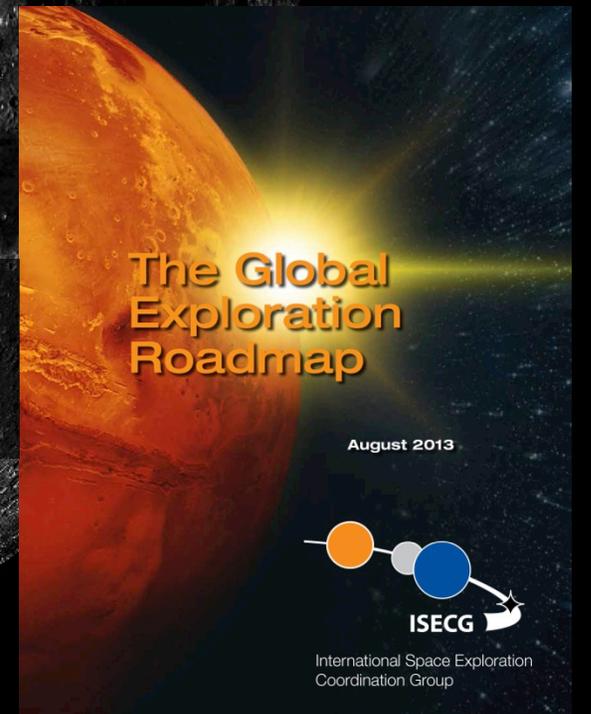


# ISECG/Global Exploration Roadmap

NASA has become involved in the Global Exploration Roadmap ([https://www.nasa.gov/sites/default/files/files/GER-2013\\_Small.pdf](https://www.nasa.gov/sites/default/files/files/GER-2013_Small.pdf)).

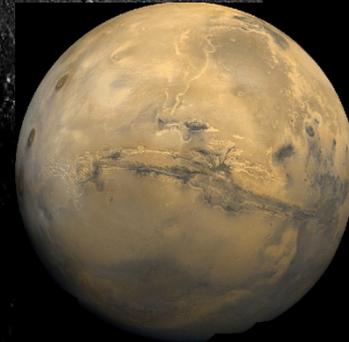
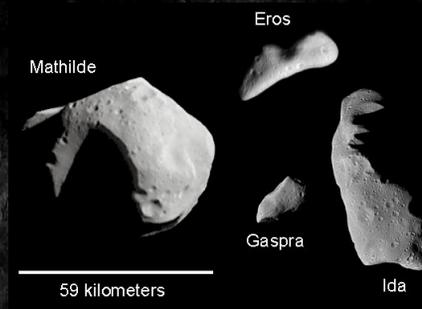
- Moon
- cis-Lunar Space
- Asteroids

Mars is the “horizon destination” so logical steps are required to get there.



# Mindset

In lean budget years it is easy to focus on exclusive destinations.  
A progressive exploration/science strategy is required.



# Logic(?)

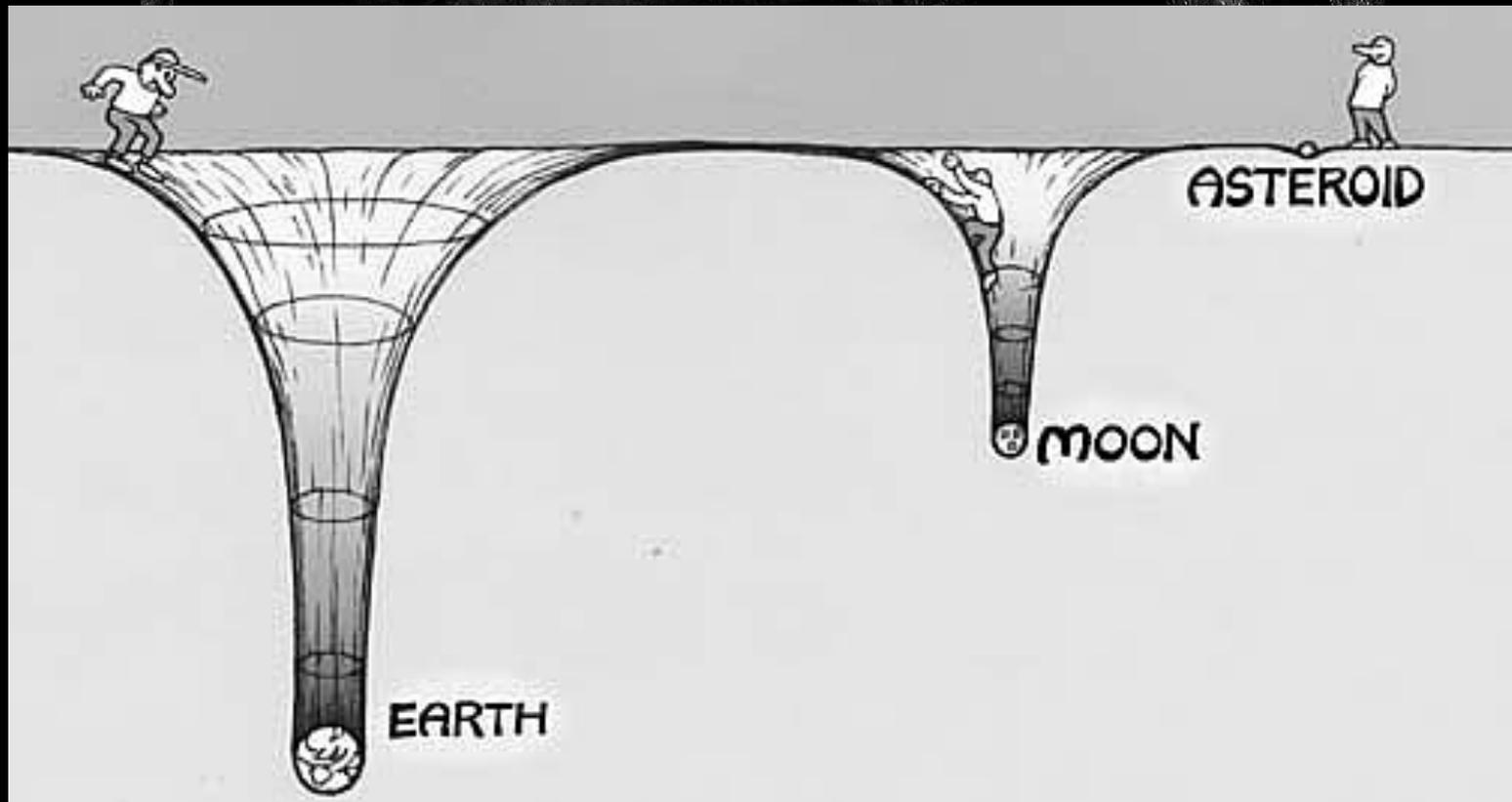
Build infrastructure/capability at a rate that is independent of annual budgets (speed up/slow down depending on budget).  
Don't have destination dates, but destination targets!  
Show a progression of capabilities regarding sending humans out from Earth.  
Be goal oriented.

# What are the Goals?

**Current USA focus:** Send humans to explore an asteroid or a boulder from an asteroid (ARM).

**International Partners:** the Moon.

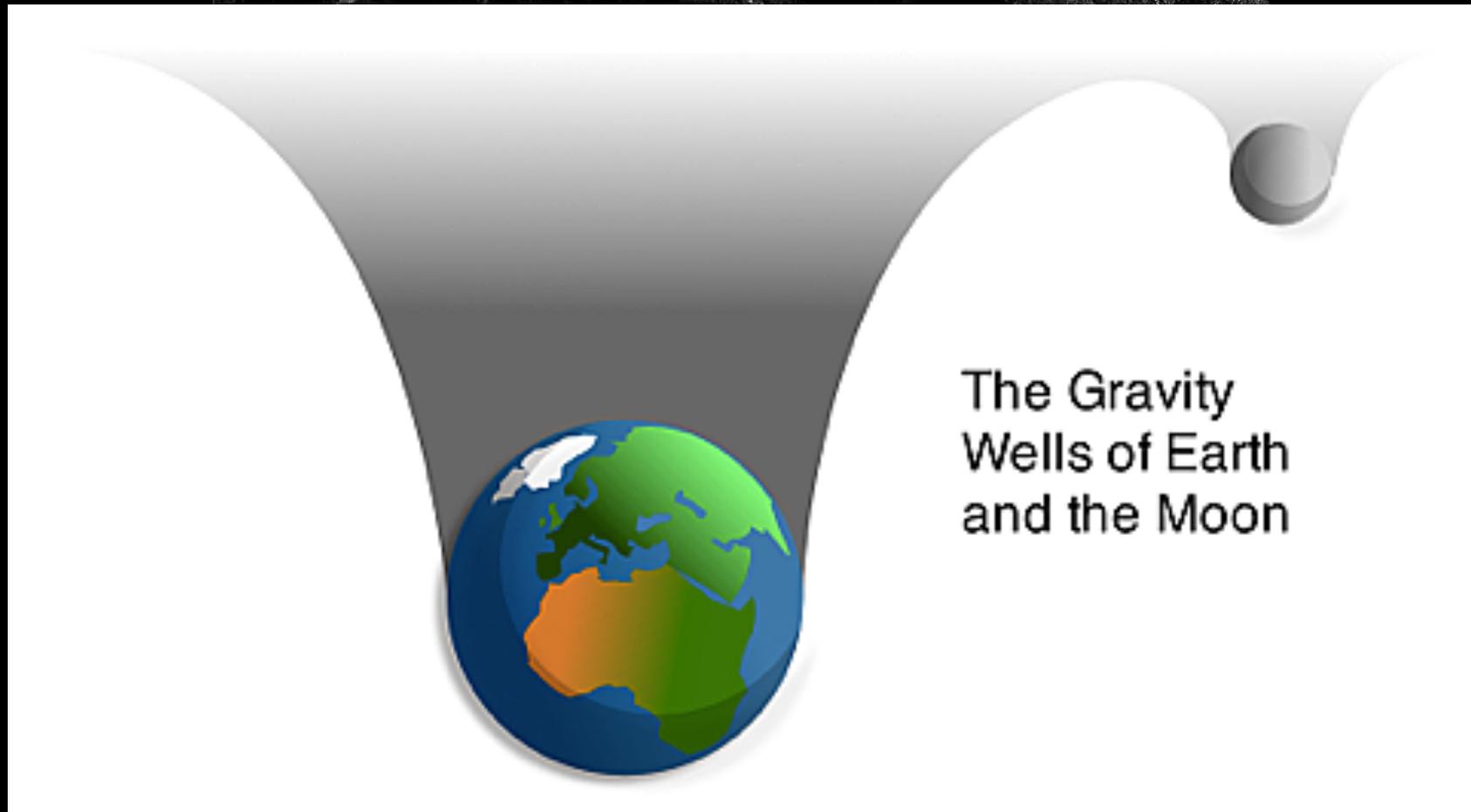
Horizon destination = Mars.



# Capabilities

Need a base to stage capabilities.

Initially Earth, but in the future it can be cis-lunar space and the Moon (lower gravity well, harvestable resources).



# Using the Moon to Enable Solar System Exploration and Science



The “*been there, done that*” negativity becomes a positive advantage making the Moon an enabling asset for Solar System exploration and science.

# Lessons from Apollo

Science was an after-thought.

No long-term goal.

**We should not repeat Apollo**, but look what we learned!

- Regolith
- Space weathering
- Seismicity
- Impacts/cratering
- Terrestrial planet evolution
- Radiation environment
- And much more!



Note the blurring of science and exploration categories in many of these!

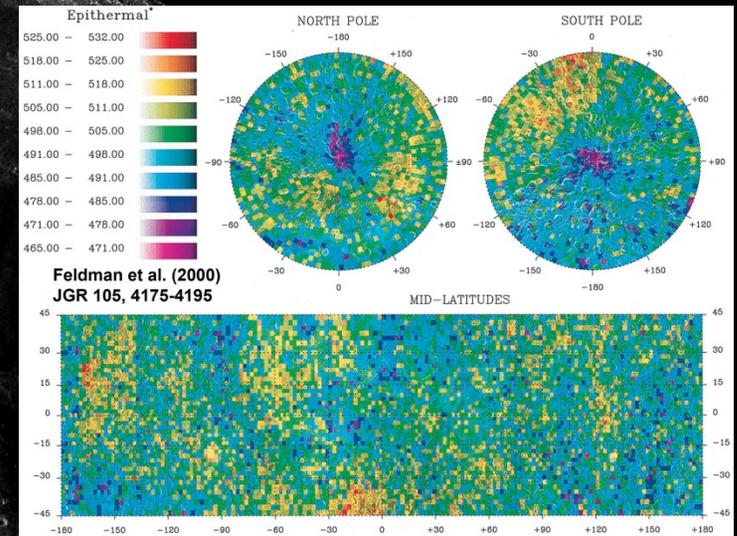
# Subsequent Missions

## 1990s = Clementine and Lunar Prospector (both USA)

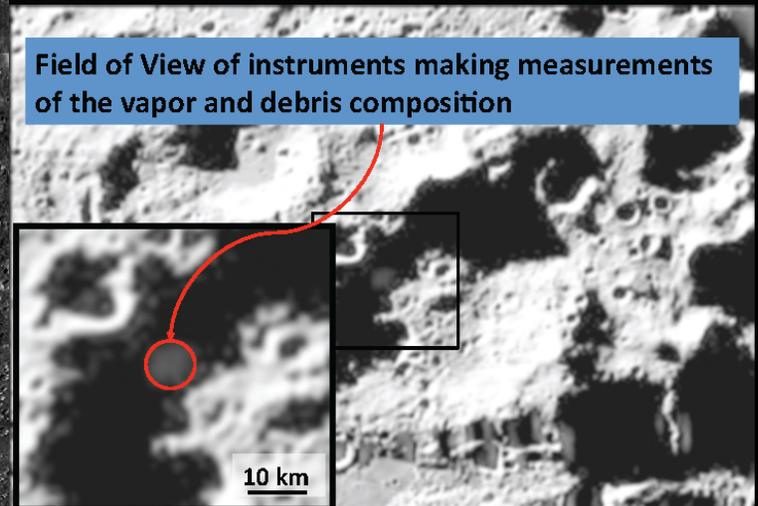
- Global coverage;
- Polar H deposits
- Cryptomare
- Much more!

## 2000s = international interest in the Moon

- SMART-1 (ESA)
- Chang'E 1, 2, 3 (China)
- Chandrayaan-1 (India)
- Selene/Kaguya (Japan)
- LRO, LCROSS, GRAIL, ARTEMIS (USA)



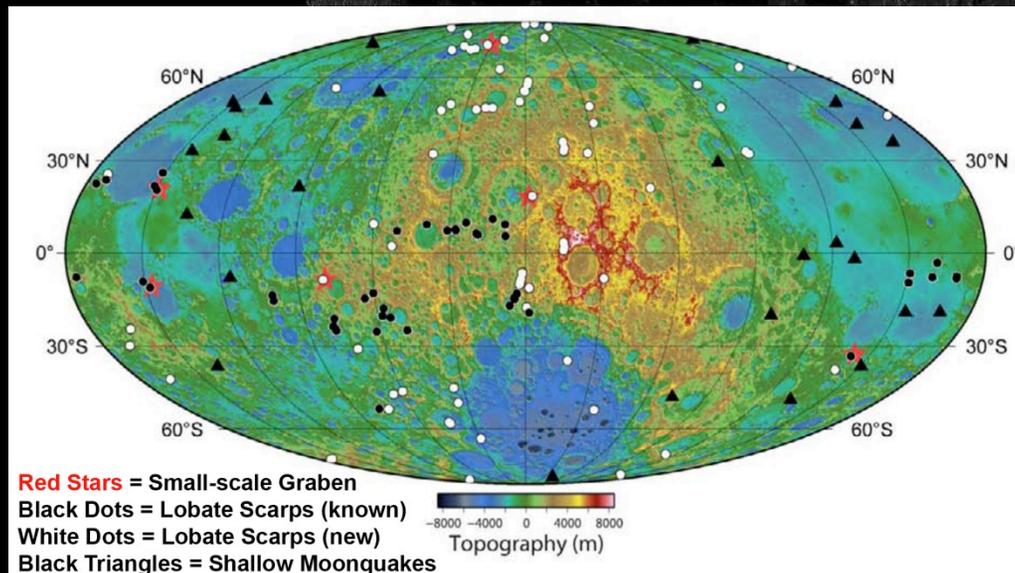
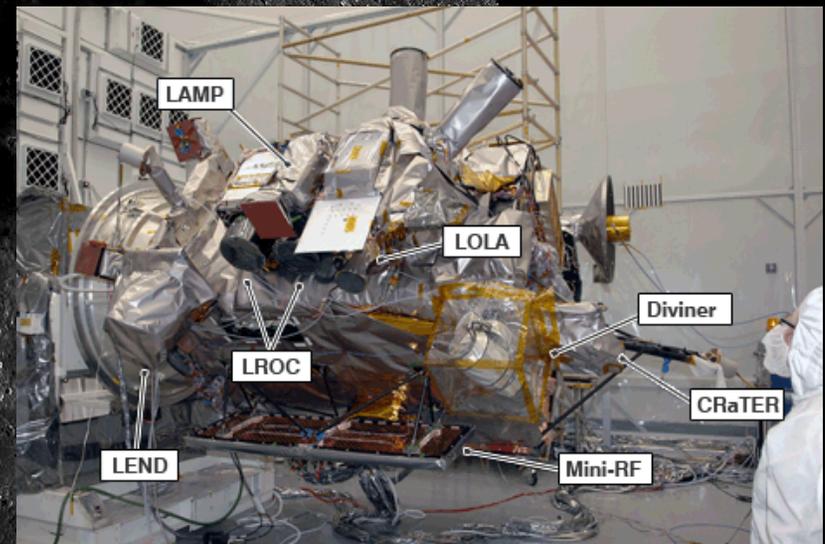
LCROSS Visible Camera Image of Ejecta Cloud



# Lunar Reconnaissance Orbiter

Exploration Enables Science and Science Enables Exploration

ESMD mission to define boulder fields, imagery, topography, resources, radiation environment in order to reduce risk to future human lunar surface missions.



Now in Extended Science Mission 2 for SMD. Same instruments!

Watters et al. (2012)  
*Nature Geosci.* doi:  
10.1038/NCEO1387

# Resource Prospector

Science Enables Exploration and Exploration Enables Science

HEOMD mission based on Lunar Prospector (SMD) and LRO (ESMD/SMD) data to find and extract lunar resources.

Science implications are huge!

2020 launch (?).

RPM meeting this Friday at Ames.



# The Moon (and cis-lunar space) as an Enabling Asset

## Proximity:

- “Ease” of access;
- Risk reduction.

## Harsh Environment:

- Test radiation shielding technologies;
- Reduced gravity (not microgravity);
- Dust.

## Long-duration testbed.

## ISRU:

- Learning to live off the land, off-planet.



# The Moon (and cis-lunar space) as an Enabling Asset



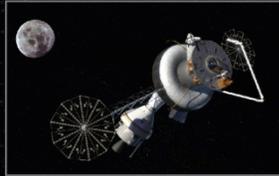
Full utilization and servicing of ISS in concert with International partners and commercial providers prepare for exploration beyond Low Earth Orbit



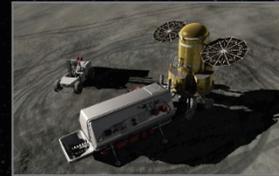
Propellant depots increase payload capability of current and future Launch Vehicles and refueling of reusable In-space Transportation



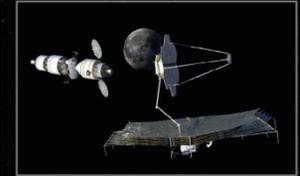
Hybrid reusable transportation infrastructure support for EM/L1/2, crew and cargo for Lunar exploration, and Satellite deployment & servicing



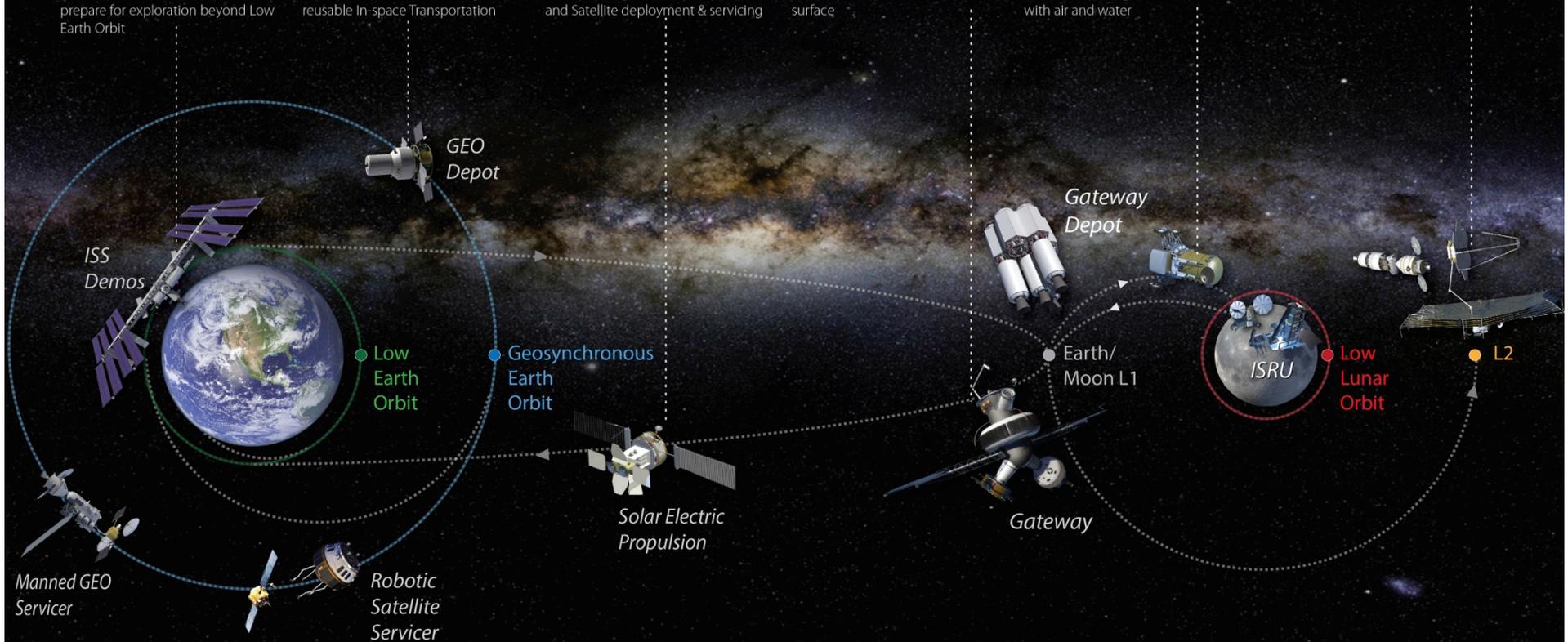
L1/L2 Gateway transportation node location for propellant depot and access to and from the Lunar surface



Lunar In-situ Resources Utilization produces water for rocket propellants and for sustaining surface operations with air and water



Construction and servicing of advanced telescopes and other In-space assets



<http://www.spudislunarresources.com/blog/after-the-vision-what-next/>

# Progressive Exploration

**2007:** LEAG tasked to develop a comprehensive Lunar Exploration Roadmap (LER).

**3 Themes:** Science, Feed Forward, and Sustainability.

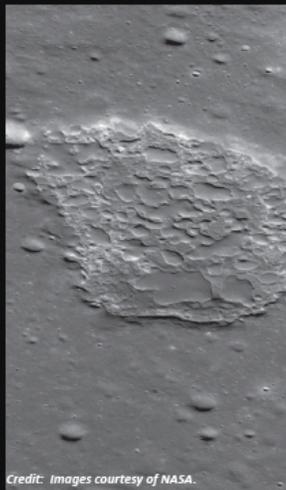
[www.lpi.usra.edu/leag](http://www.lpi.usra.edu/leag)

The Lunar Exploration Roadmap, jointly developed by engineers, planetary scientists, and policymakers, is the cohesive strategic plan for using the Moon and its resources to enable the exploration of all other destinations within the solar system on a sustained basis by leveraging incremental and affordable investments in lunar infrastructure.

Implementing the Roadmap will preserve American leadership, engage and inspire the public, open the space frontier to the energy and vitality of commercial enterprise, and enhance international partnerships as well as world security.

## FOLLOW THE ROADMAP

<http://www.lpi.usra.edu/leag/roadmap>



Credit: Images courtesy of NASA.

## THE MOON GATEWAY TO THE SOLAR SYSTEM

**PROGRESS IS NOT A SHOT IN THE DARK, BUT A SERIES OF LOGICAL STEPS.**

— Robert H. Goddard



## OPEN THE GATEWAY TO THE SOLAR SYSTEM

### SUSTAIN

A FOOTHOLD ON THE NEXT FRONTIER

Use the Moon to learn how to live and work productively off-planet for increasing periods, enabling human settlement.

The Moon has abundant material and energy resources that can be used to make ambitious solar system exploration more cost-effective. Lunar resources offer an enduring opportunity for commercial investment and economic growth. Innovative public-private partnerships growing from initial government investment sustain infrastructure and create new spacefaring opportunity.

### DISCOVER

KNOWLEDGE ON A NEW WORLD

Use the Moon for scientific research that addresses fundamental questions about the Moon, the solar system, and the universe.

A sustained program of lunar exploration will yield significant scientific and technological advances. The Moon retains a record of the formation, evolution, and impact history of Earth and the other terrestrial planets, as well as an otherwise inaccessible record of the Sun's evolution and history. The Moon provides a unique and stable platform for observations of Earth, the Sun, and

### PIONEER

THE TRAIL TO MARS AND BEYOND

Use the Moon to prepare for future missions to Mars and other destinations beyond

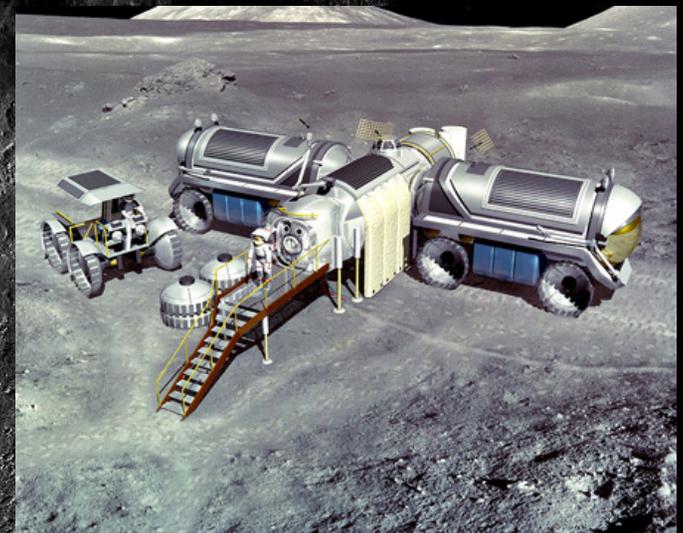
The Moon is a convenient deep space test bed that can be used to reduce cost and risk by testing technologies, systems, and operations. This lunar training ground enables sustained human space exploration beyond low Earth orbit. The Moon's combination of radiation, hard vacuum, and low gravity provides a unique laboratory in which to study the physiological, biological, and biomedical aspects of long-duration space travel.

# Feed Forward

## The LER Enables Solar System Exploration and Science

Mars/Small Body Risk Reduction Value: How well do the candidates address the key risk reduction areas identified through NASA's robotic and human Mars/Small Body mission planning studies;

Lunar Platform Value: Do candidates leverage the unique attributes of a lunar program to achieve success – or – would other platforms be more effective from a technical/cost perspective.



# Feed Forward

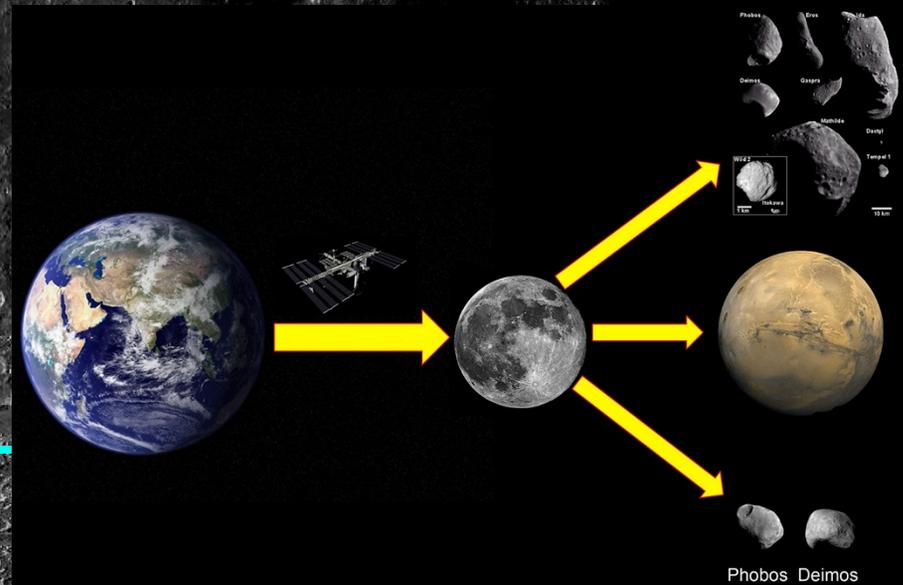
**GOAL FF-A:** Identify and test technologies on the Moon to enable robotic and human solar system science and exploration.

**GOAL FF-B:** Use the Moon as a test-bed for missions operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.

**GOAL FF-C:** Preparing for future missions to other airless bodies.

**The LER enables Human Solar System Exploration – and therefore Science!**

[www.lpi.usra.edu/leag](http://www.lpi.usra.edu/leag)



# **The Moon Enabling Human Solar System Exploration & Science**

## **Advantages**

- Testing bioregenerative (life-support) technologies that are needed to support wastewater processing, air revitalization and food production (closed loop??).
- Perform long-duration testing of an integrated surface life support system that is needed to simulate Mars surface stay times exceeding 500 days.
- Testing countermeasure technologies that need to be tested so as to assure human performance remains at an acceptable standard.

# The Moon Enabling Human Solar System Exploration & Science

## Advantages

- Testing surface mobility systems (range, duration, terrain, time).
- Testing surface fission power system technologies that should be capable of being autonomously deployed and able to initiate/sustain power generation without human interaction.
- Testing monolithic habitat technologies on the lunar surface that incorporate the capability for autonomous deployment and operations without human intervention.



# The Moon Enabling Human Solar System Exploration & Science

## Advantages

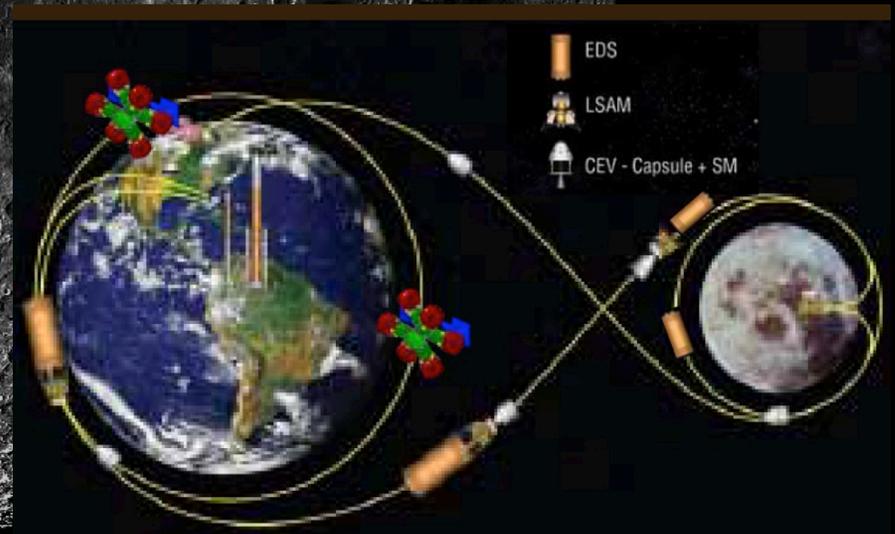
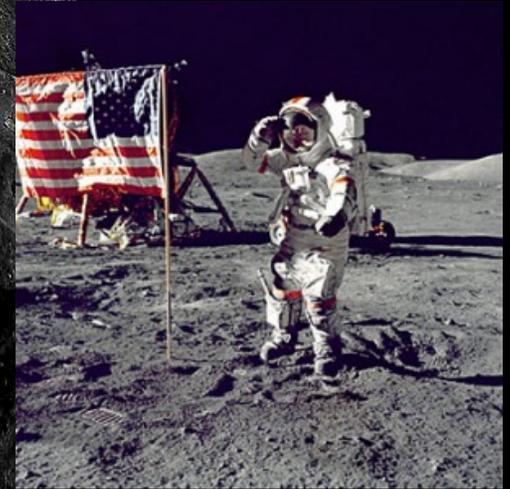


- Testing dust mitigation technologies to prevent dust from interfering with mechanical systems and causing health problems for astronaut crews.
- Testing radiation shielding technologies outside of the Earth's magnetosphere.
- Testing forward and backward planetary protection technologies to prepare for human and robotic operations on Mars.
- Conduct a Mars surface mission simulation on the Moon.

# The Moon Enabling Human Solar System Exploration & Science

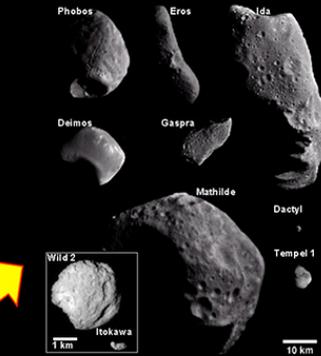
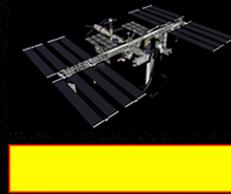
## Advantages

- cis-lunar refueling/staging posts.
- Use lunar resources for fuel & life support.
- Commercial space opportunities.
- American leadership.



# The Message

The Moon is not the end-game!  
It is an enabling asset as the gateway  
for humans to explore the Solar  
System!



Human Solar System Exploration (&  
Science) requires international and  
commercial partnerships (see the LER!)



# The Message

From scientific research, we know that the Moon has resources that could enable in-depth lunar and Solar System exploration by humans.

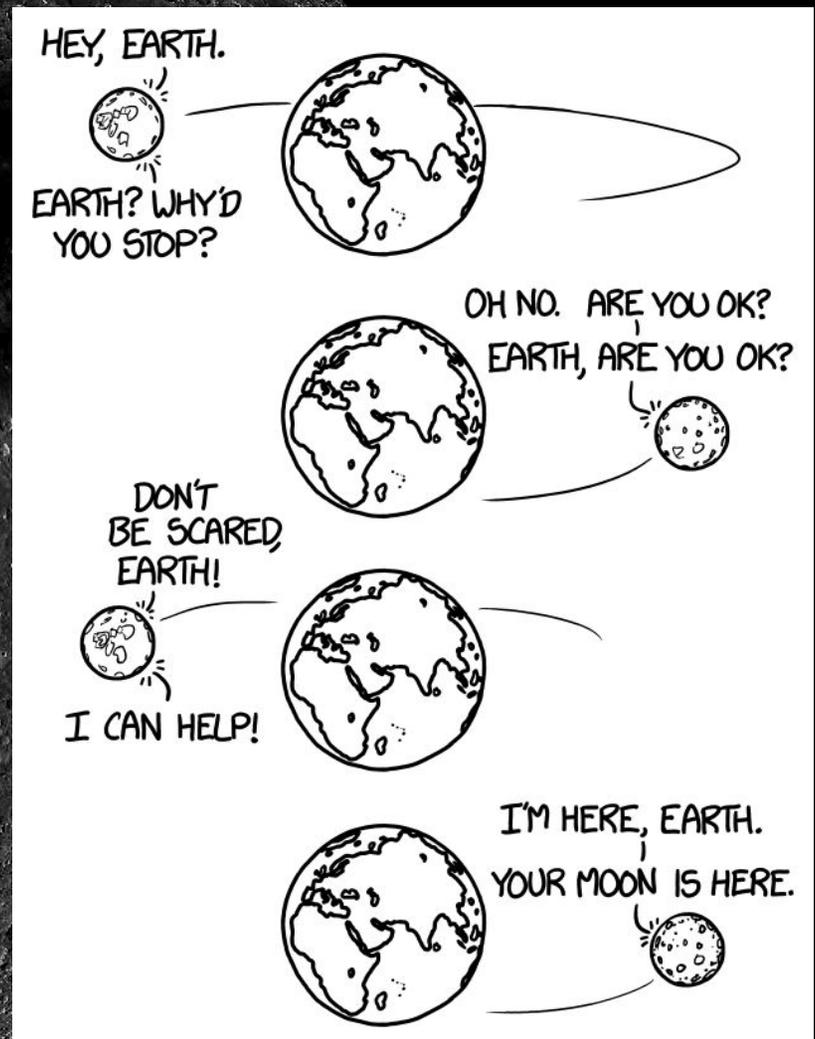
We need to develop a long-term and international human space exploration plan that allows humans to move out into the Solar System to multiple destinations.



# The Message

**LEARN FROM APOLLO!** No more “flags-and-footprints”.

- Develop an architecture that is relevant for multiple destinations and evolvable.
- Do not abandon assets.
- Develop international and commercial partnerships early.
- Have target destinations/ milestones, NOT dates.
- For the Moon, “*been there, done that*” is a major advantage!



# Questions?

The Big Mike “you got a problem with that?” photo!

