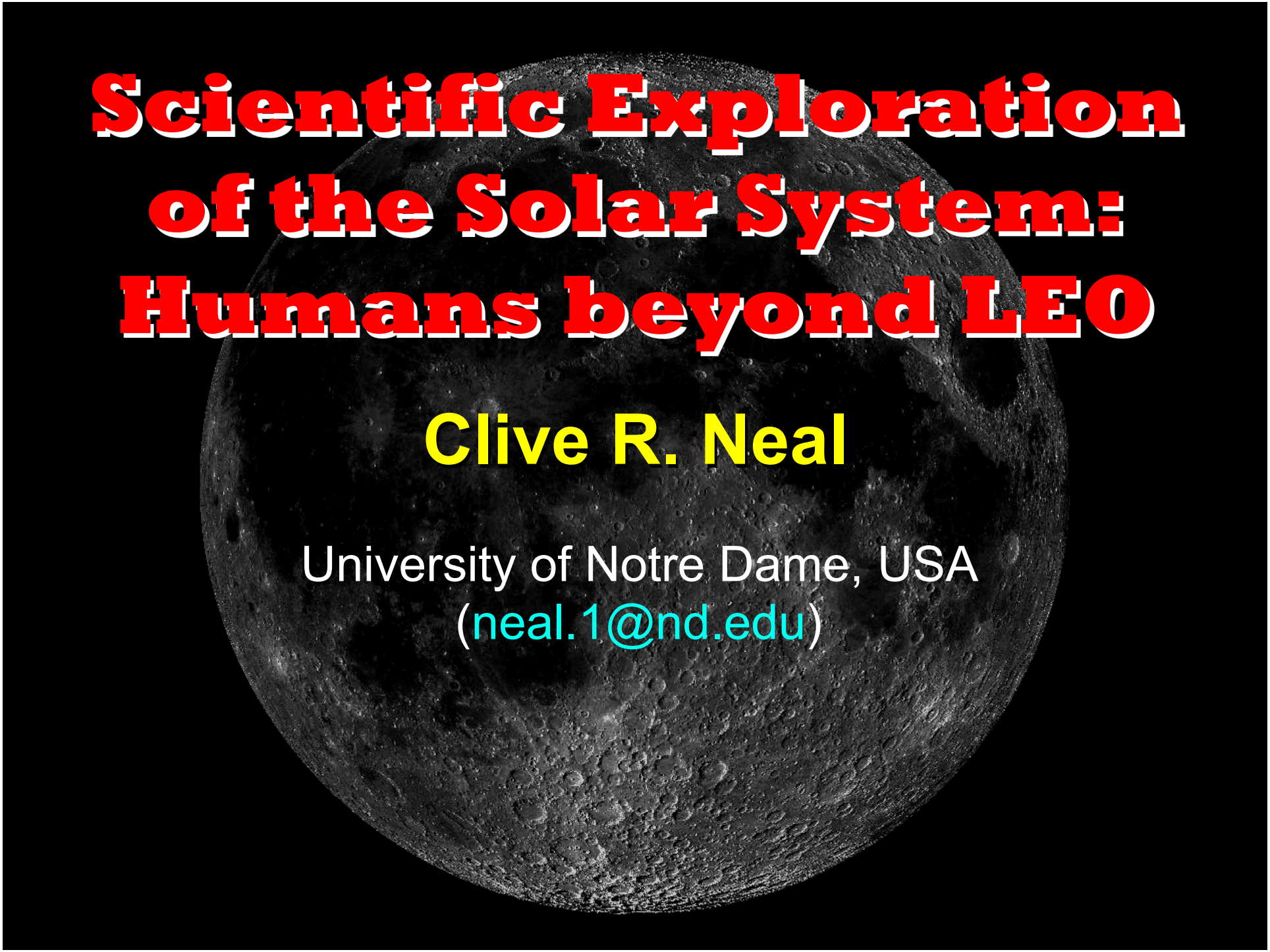


Scientific Exploration of the Solar System: Humans beyond LEO

Clive R. Neal

University of Notre Dame, USA
(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)

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.

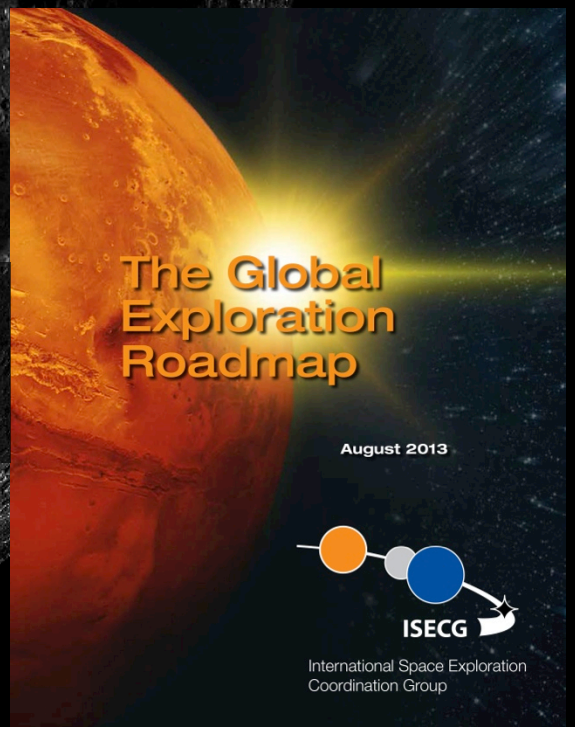
That Jaded Feeling!

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*).

- Moon
- cis-Lunar Space
- Asteroids

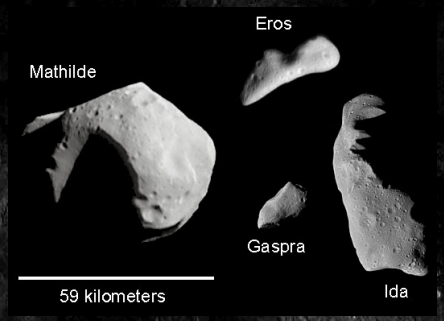
Mars is the "horizon destination" so logical steps are required to get there.



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.

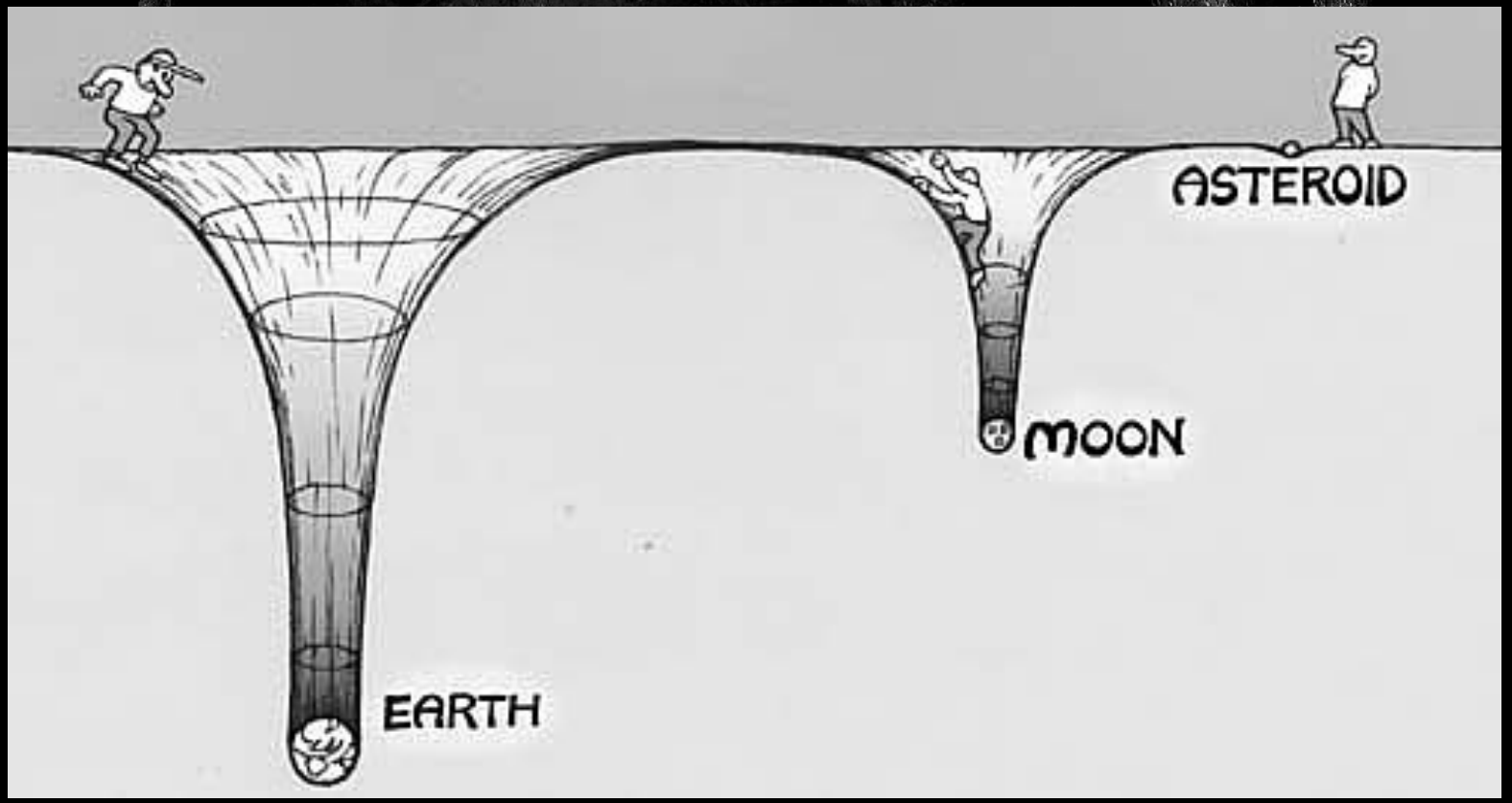
Be goal oriented.

What are the Goals?

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

International Partners: the Moon.

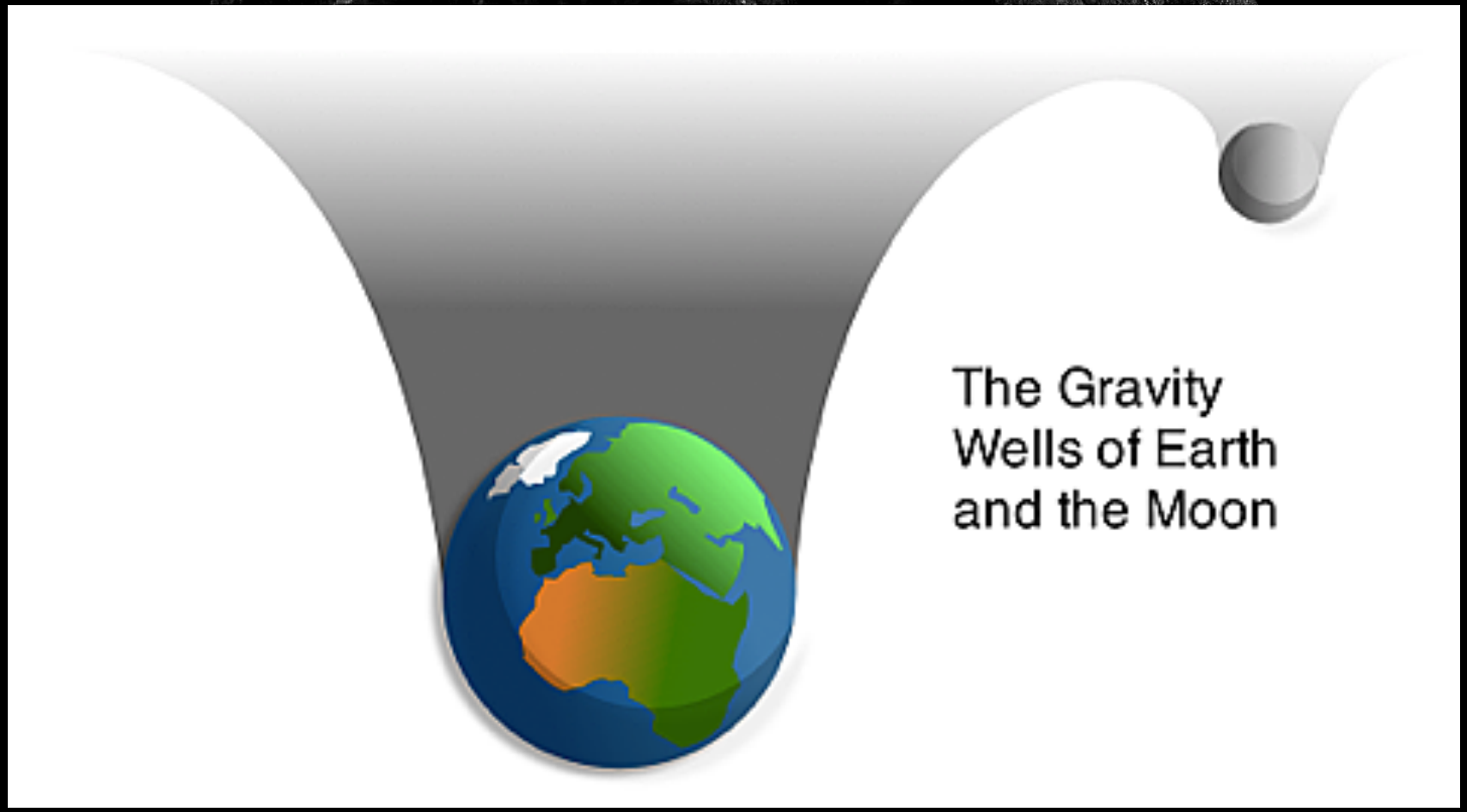
Horizon destination = Mars.



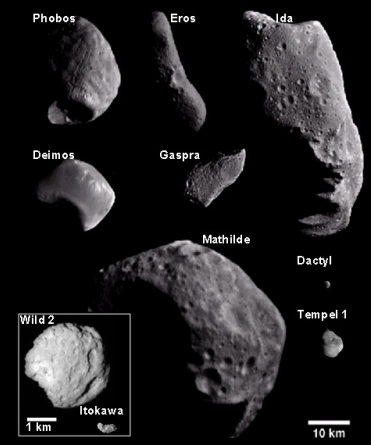
Capabilities

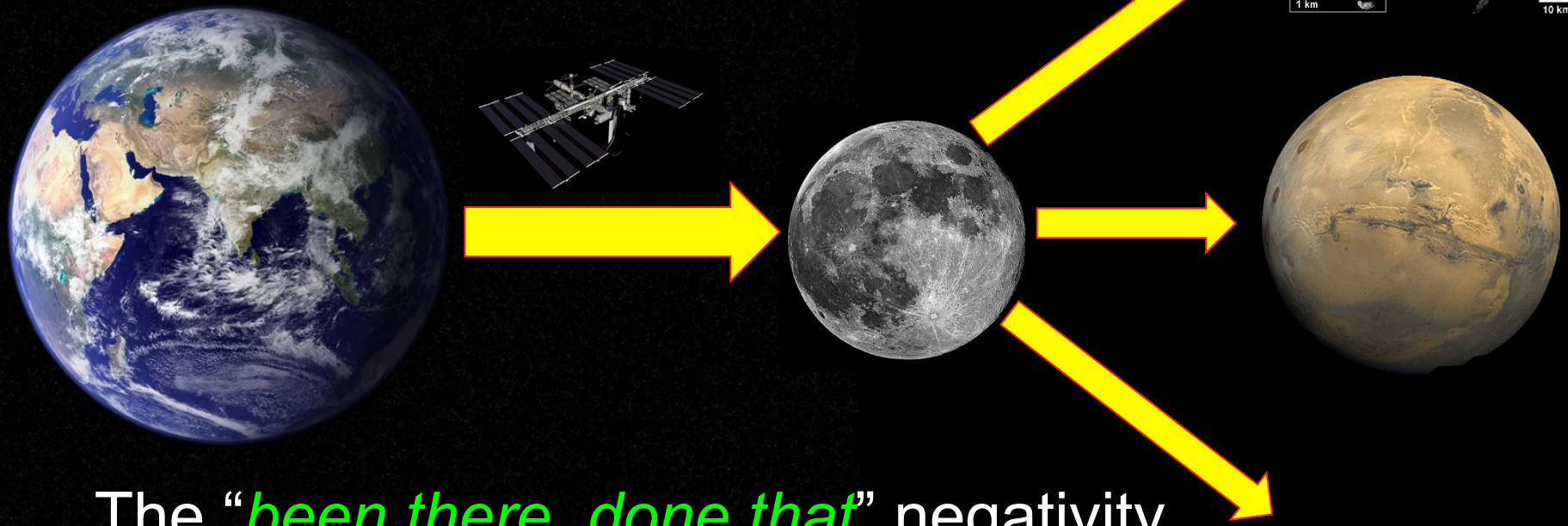
Need a base to stage capabilities.

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

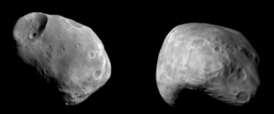


Using the Moon to Enable Solar System Exploration and Science





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



Phobos Deimos

Lessons from Apollo

Science was an after-thought.

No long-term goal.

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

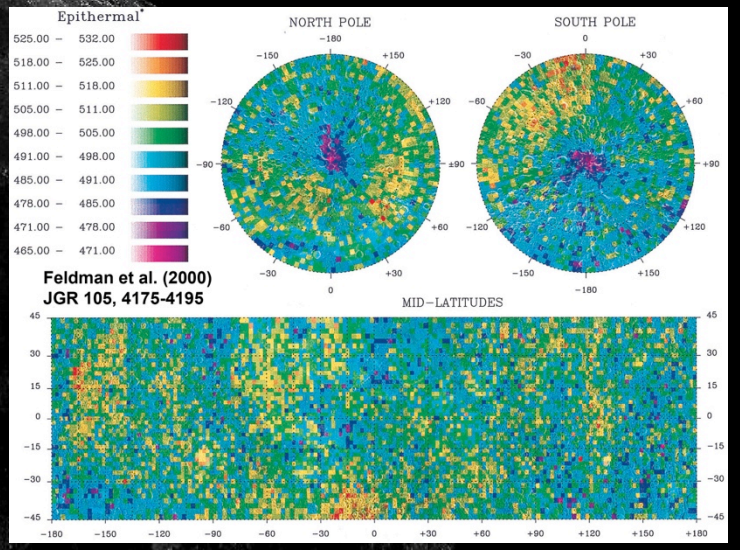
- Regolith
- Space weathering
- Seismicity
- Impacts/cratering
- Terrestrial planet evolution
- Radiation environment
- And much more!

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

Subsequent Missions

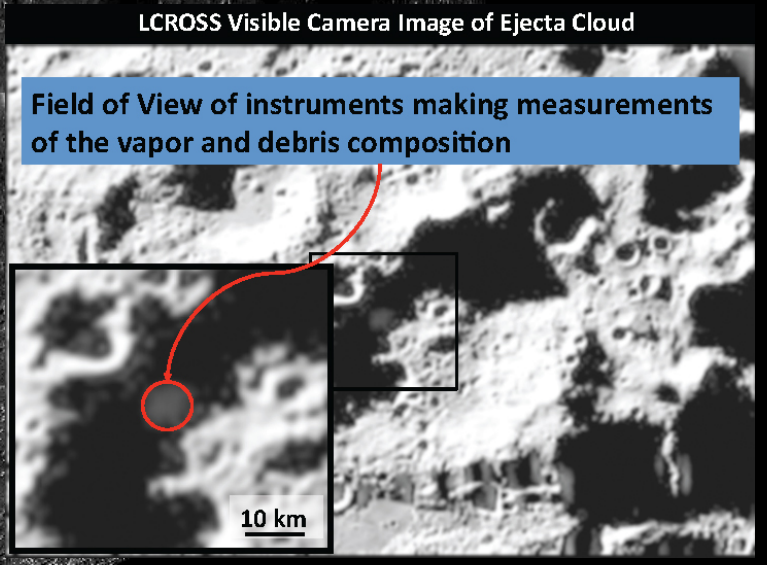
1990s = Clementine and Lunar Prospector (both USA)

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



2000s = international interest in the Moon

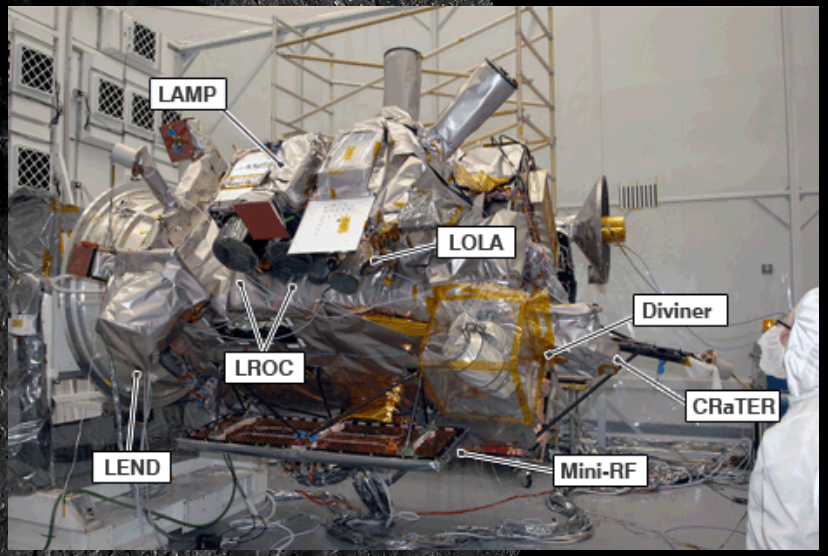
- SMART-1 (ESA)
- Chang'E 1, 2, 3 (China)
- Chandrayaan-1 (India)
- Selene/Kaguya (Japan)
- LRO, LCROSS, GRAIL, ARTEMIS (USA)

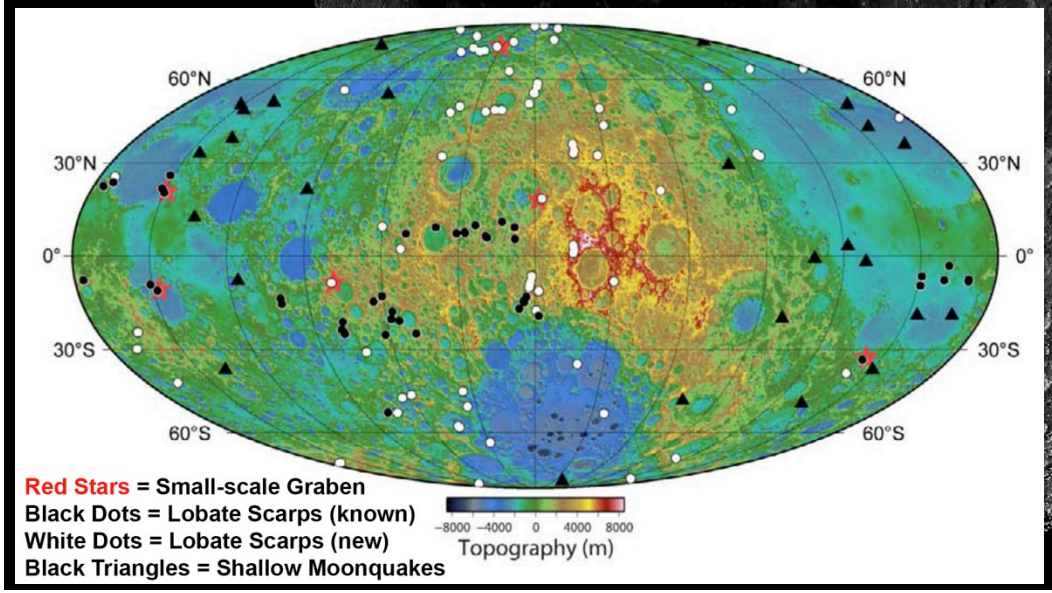


Lunar Reconnaissance Orbiter

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/NGEO1387

Resource Prospector

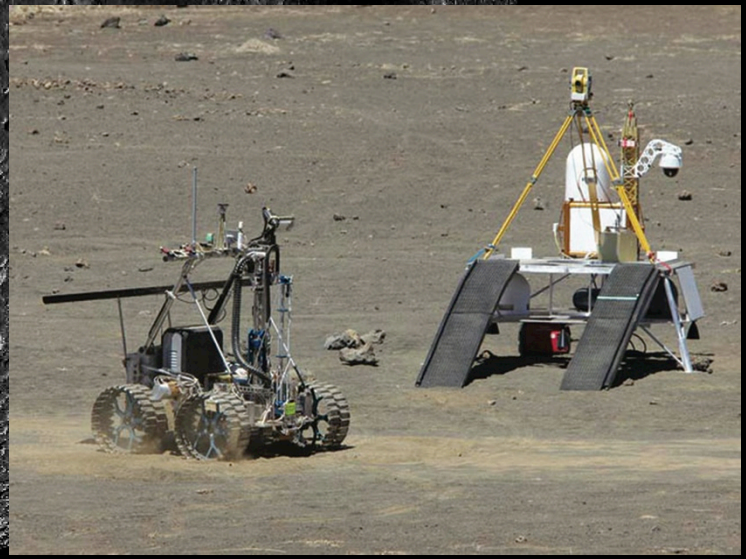
Science Enables Exploration and Exploration Enables Science

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

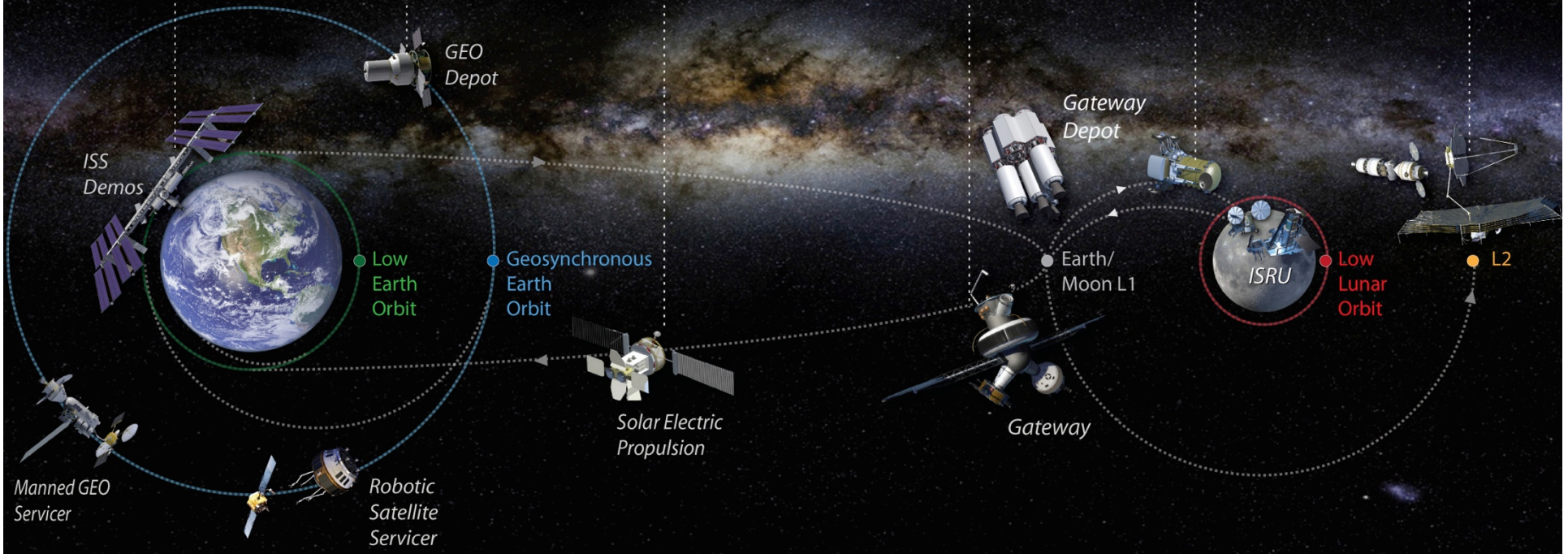
Propellant depots increase payload capability of current and future Launch Vehicles and refueling of reusable In-space Transportation

Hybred 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



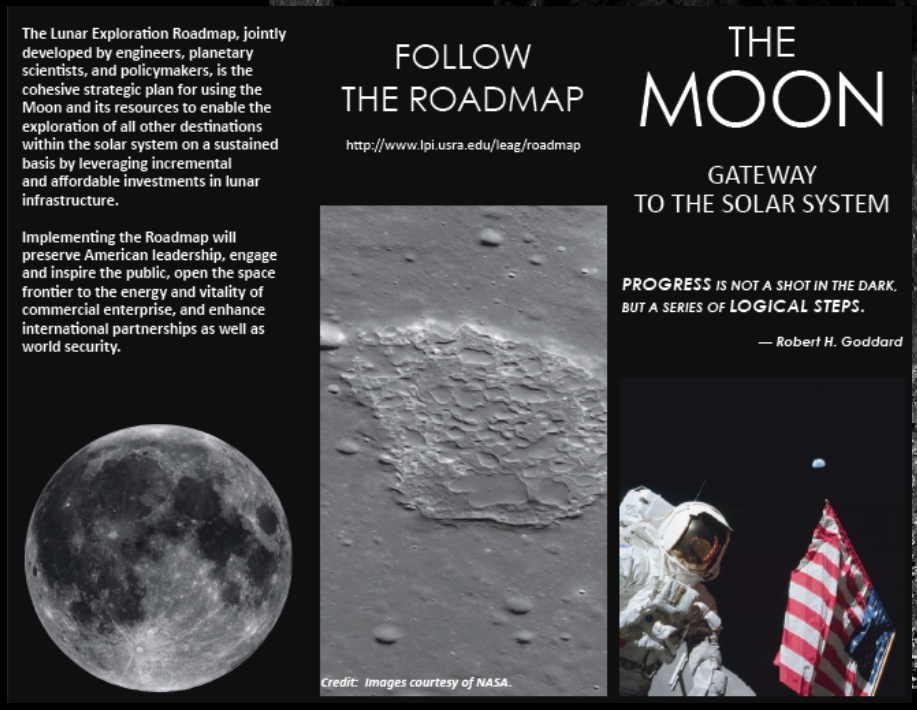
http://www.spudislunarresources.com/blog/after-the-vision-what-next/

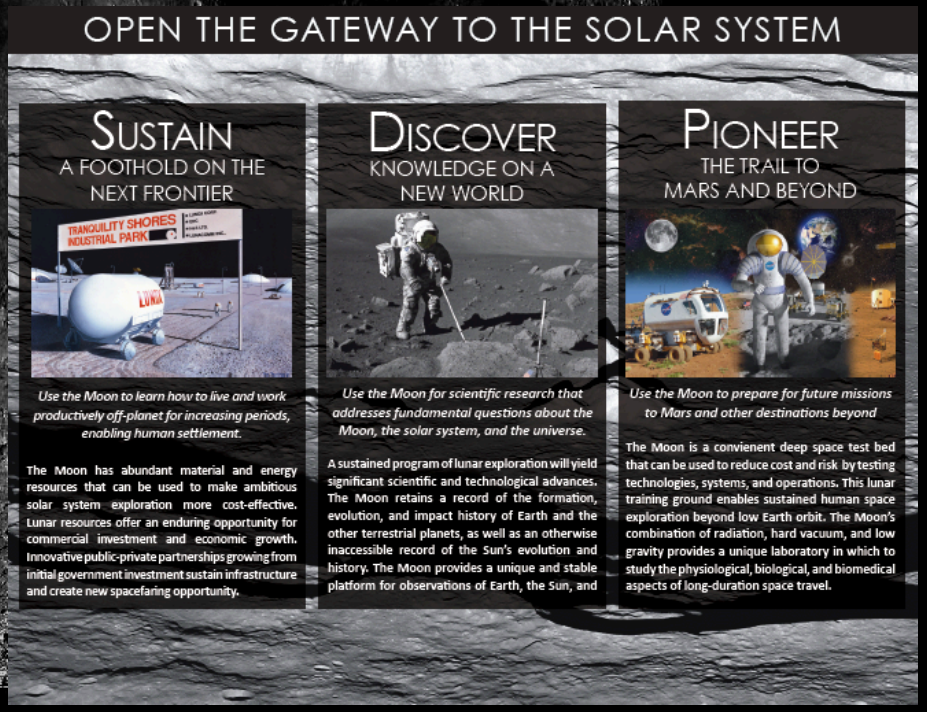
Progressive Exploration

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

3 Themes: Science, Feed Forward, and Sustainability.

www.lpi.usra.edu/leag



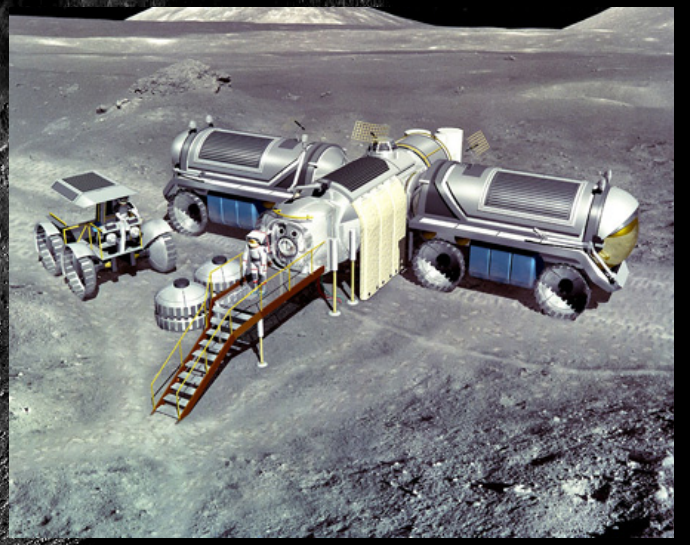


Feed Forward

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.



www.lpi.usra.edu/leag

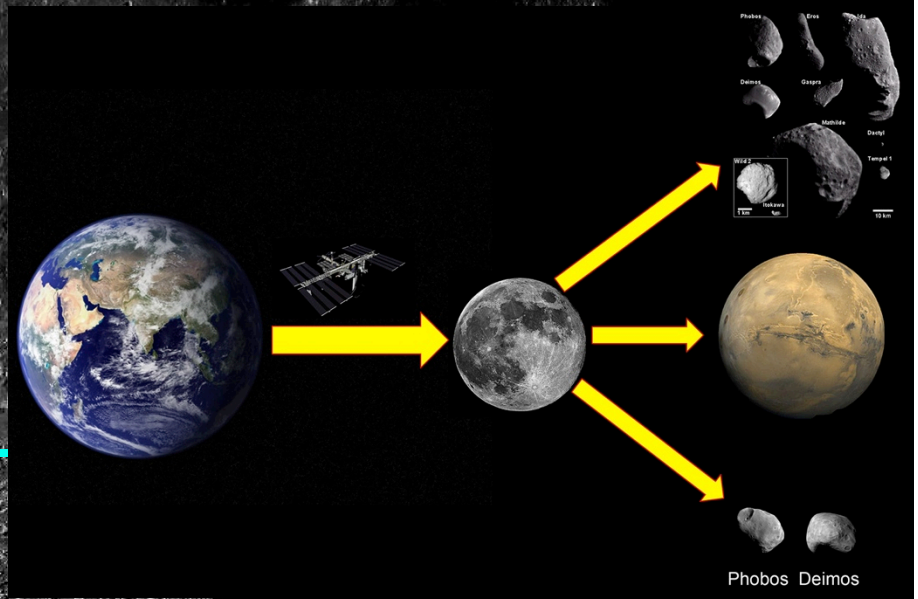
Feed Forward

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

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

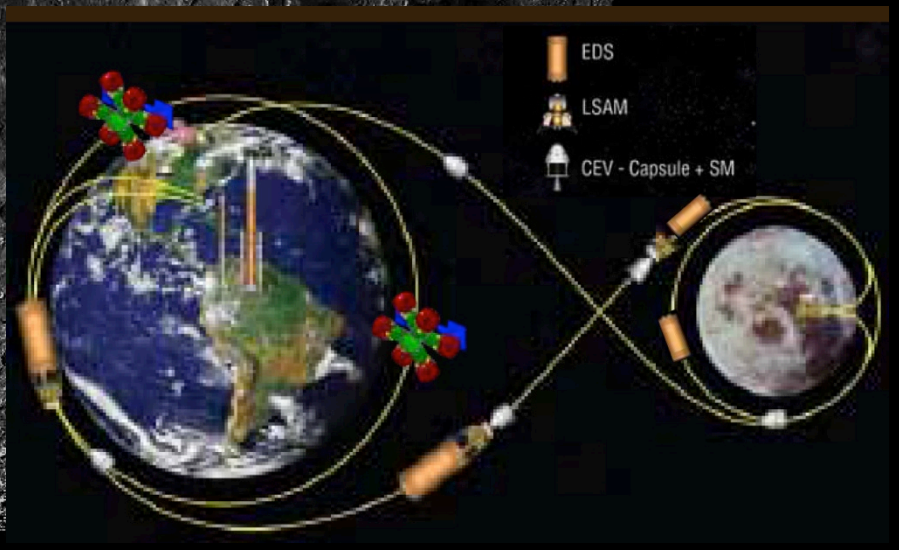
Advantages

- 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

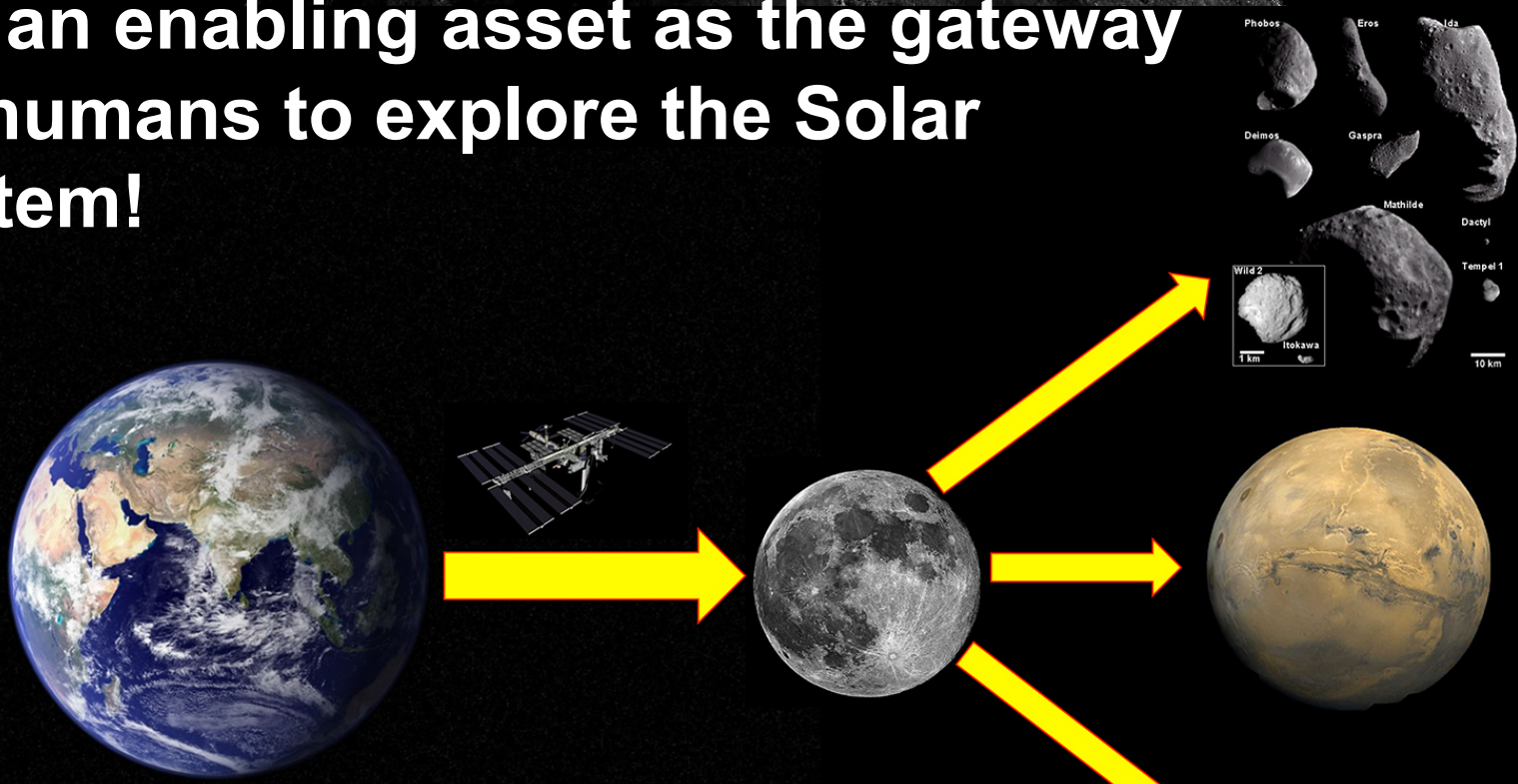
Advantages

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

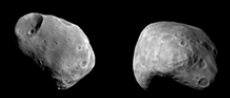


The Message

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!)



Phobos Deimos

The Message

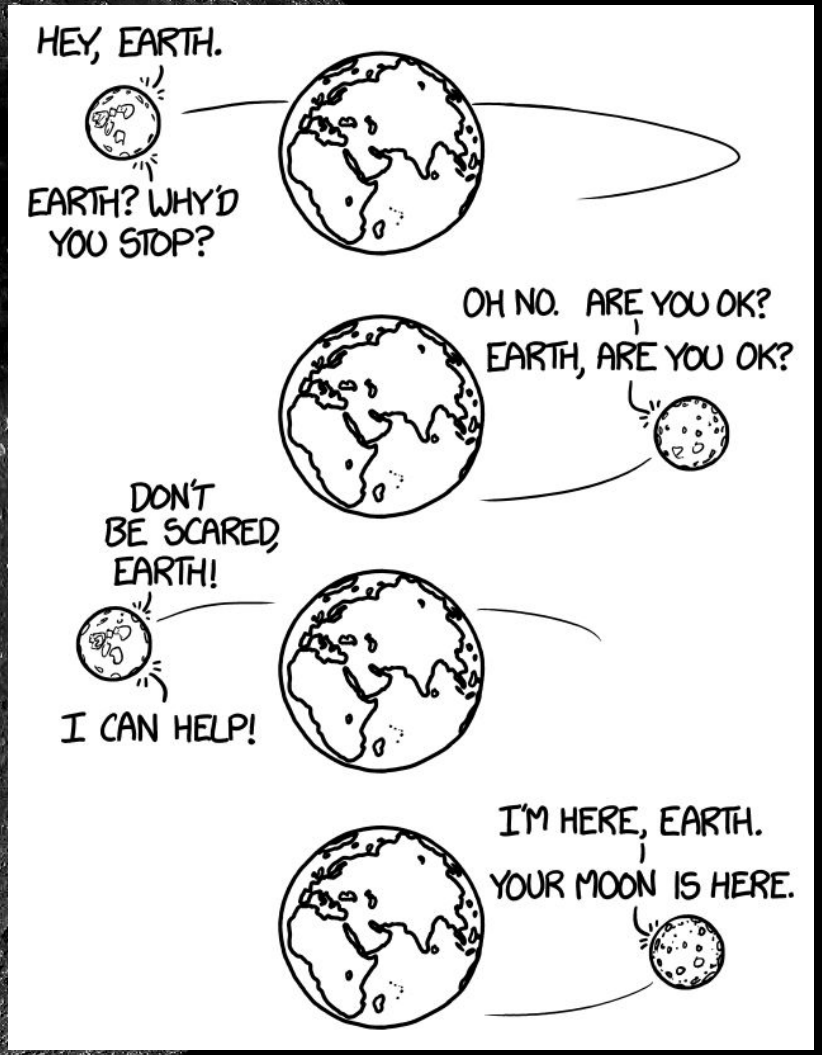
From scientific research, we know that the Moon has resources that could enable in-depth lunar and Solar System exploration by humans.

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!