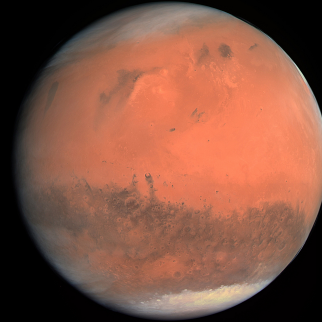
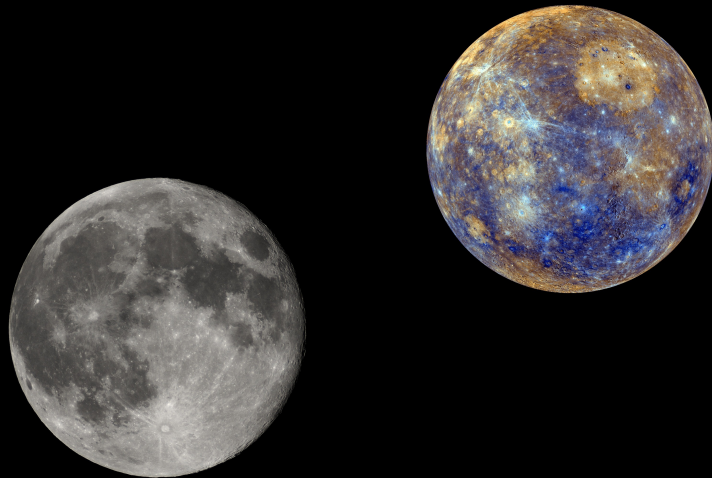


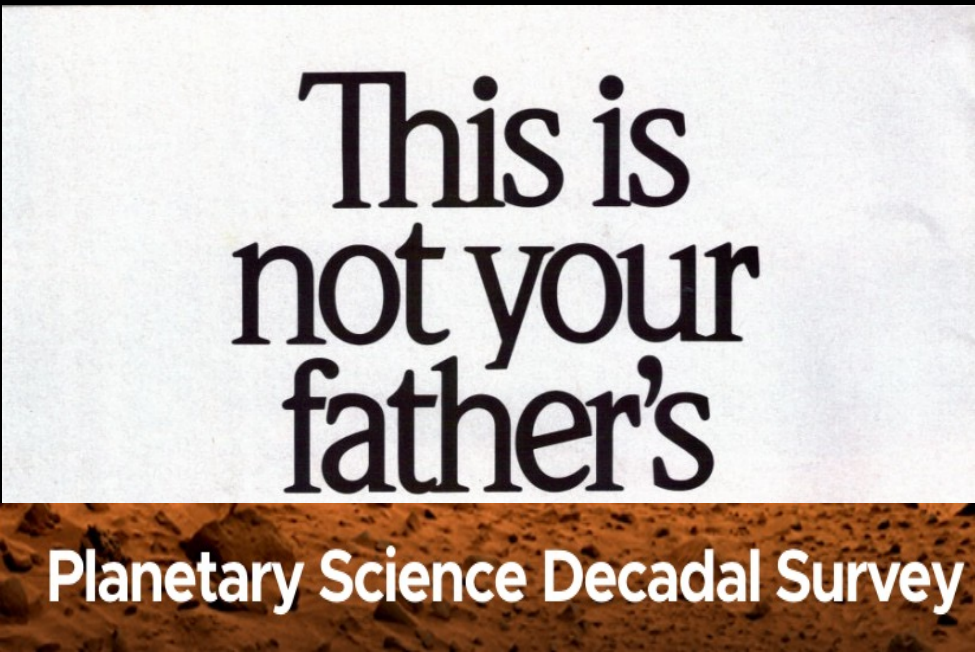
# Scientific, Technological and Programmatic Aspects of ISRU on the Moon and Mars

Angel Abbud-Madrid  
Director, Center for Space Resources  
Colorado School of Mines



*Decadal Survey of Planetary Science Panel  
on the Moon, Mercury, and Mars*

National Academy of Sciences, Engineering and Medicine  
August 6, 2021



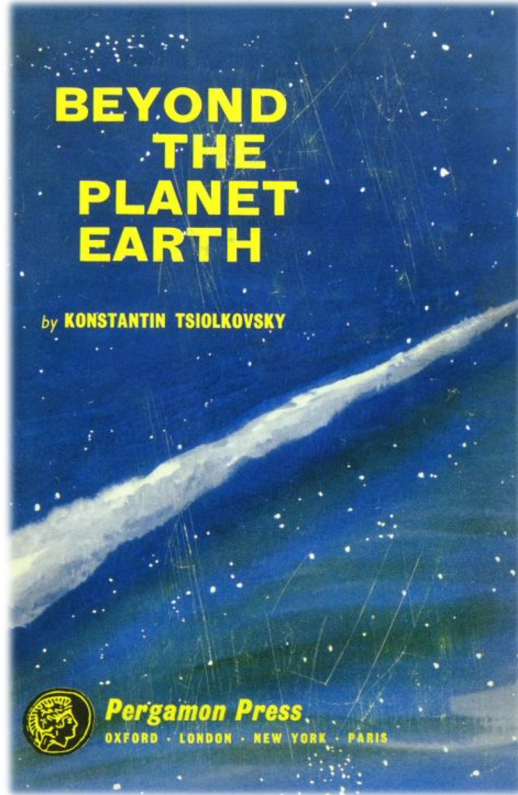
This is  
not your  
father's

**Planetary Science Decadal Survey**

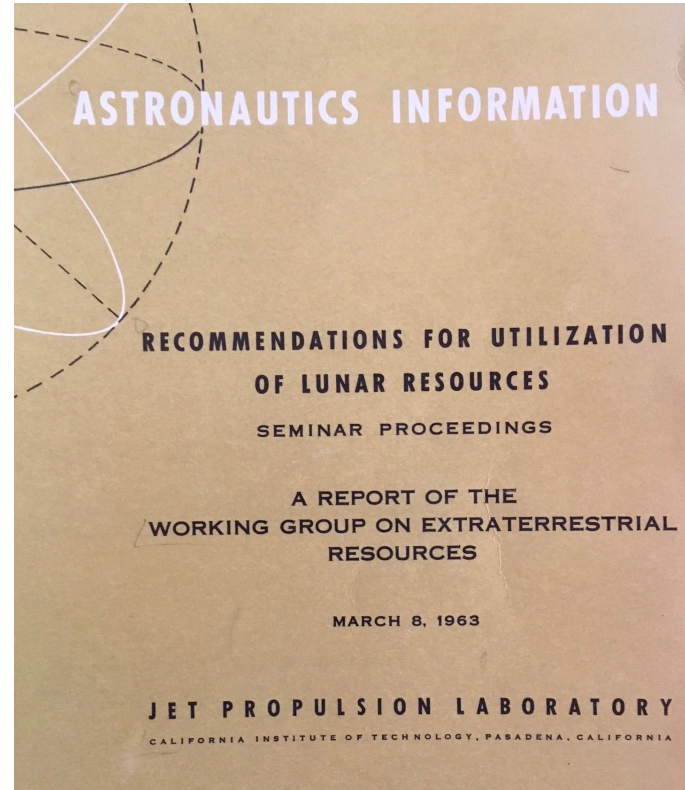
- Many new factors and players to consider
- Challenges, yes, but many opportunities through collaboration:
  - More science
  - Faster results
  - Lower cost

# Space Resources: a field of interest older than the space program

**1920**

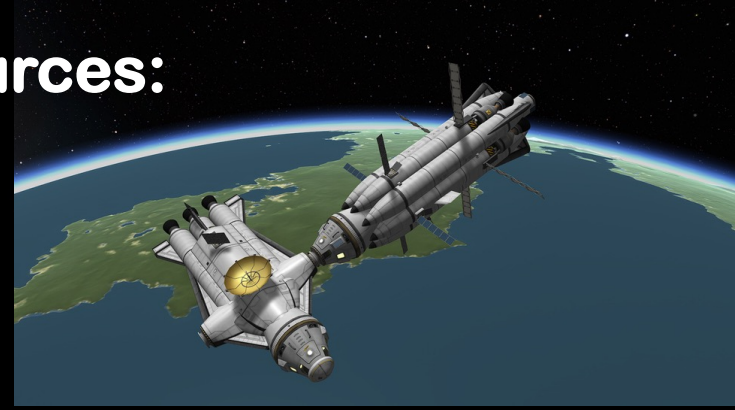


**1962**

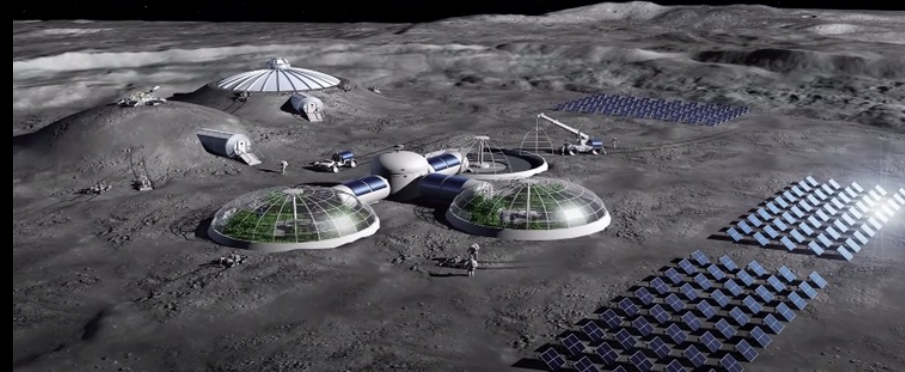


# Recent rising interest on space resources:

## \* The New Space Economy



## \* Cislunar activities



## \* Lunar and planetary bases



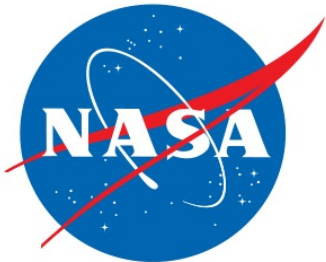
# Rising interest within US government (not just NASA anymore):



[Space.com](#) > [Tech](#)

## The US Geological Survey Is Getting Serious About Space Resources and Mining

By Leonard David, Space.com's Space Insider Columnist | September 4, 2018 07:00am ET

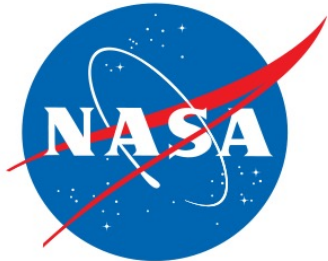


## Commerce Department to create "SPACE Administration"

by Jeff Foust — May 27, 2018



# Rising interest around the world (not just the US anymore):



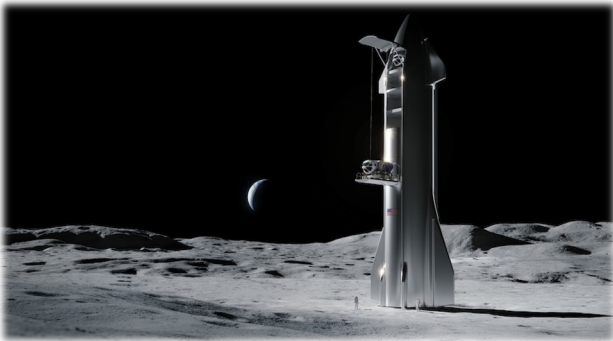
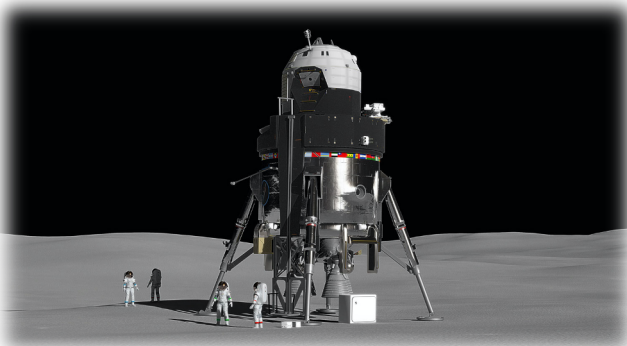
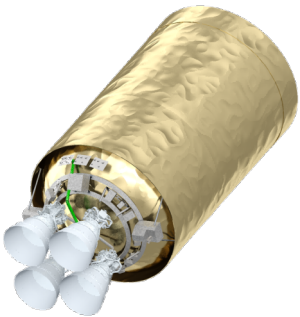
United Arab Emirates

وكالة الإمارات للفضاء  
UAE SPACE AGENCY

Australian  
Space Agency



Rising interest in the private space sector (not just the government anymore):



# Rising interest in other sectors (not just aerospace anymore):





# Welcome to the next space race!



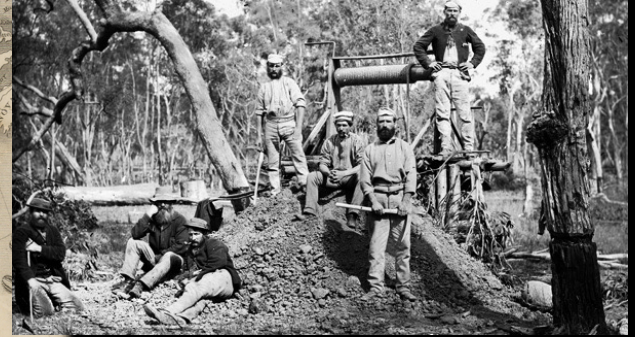
Planetary Science Decadal Survey

=



**after 1849  
gold rush**

Resource extraction activity, infrastructure build-up,  
and increased transportation by many players on  
areas of scientific and commercial interest



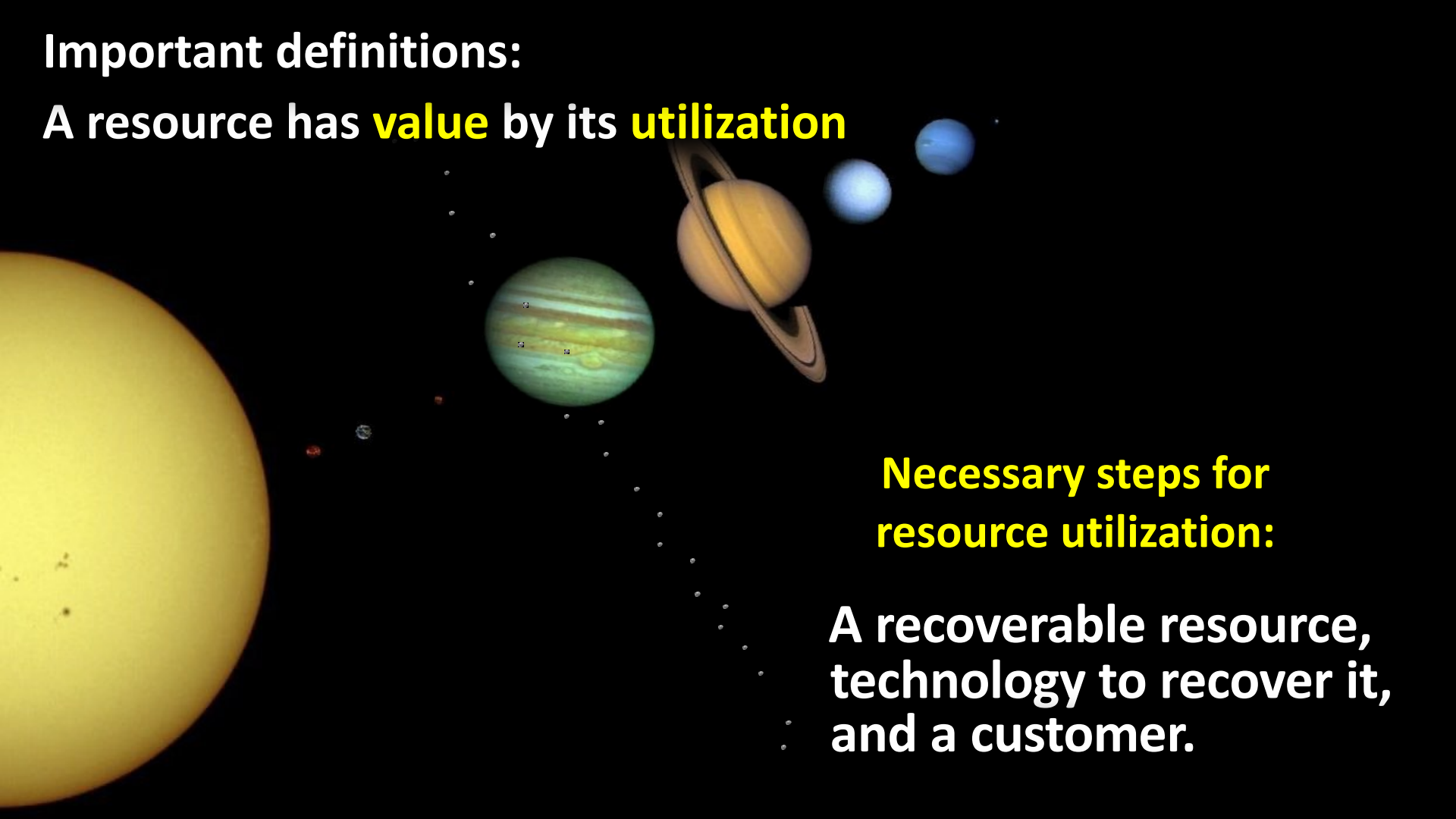
## Topics for discussion

- 1) What measurements are needed to inform ISRU plans but are not presently in hand?
- 2) What are the systems, interfaces, and organizational structures that exist or should be created to enable effective planning and execution of these measurements?
- 3) Recommend a path forward ...



**Important definitions:**

A resource has **value** by its **utilization**



**Necessary steps for  
resource utilization:**

**A recoverable resource,  
technology to recover it,  
and a customer.**



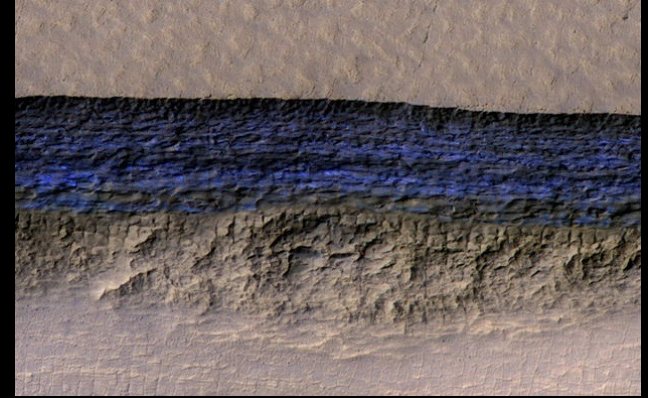
# Main resource of interest on Mars: water

50° N

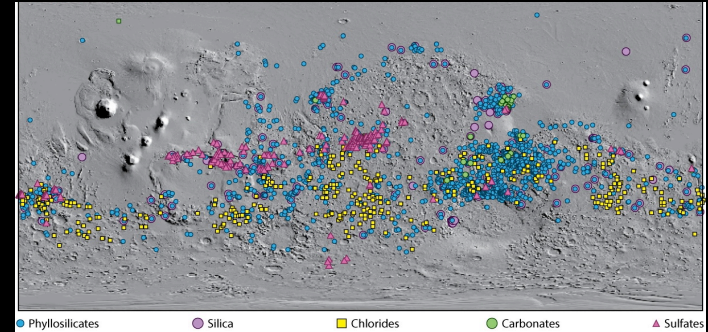
Potential sources of water  
(NASA as customer):



50° S



Subsurface ice



Hydrated minerals



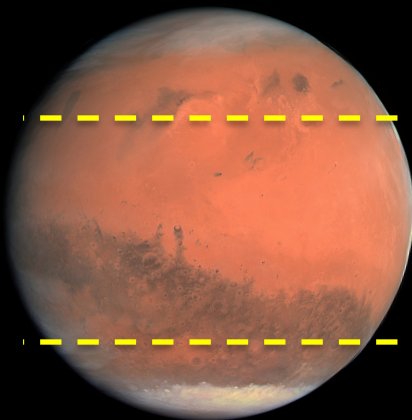
# First Landing Site/Exploration Zone Workshop for Human Missions to the Surface of Mars

October, 2015

## Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study



50° N



50° S

### Parameters:

- WHERE? Between +/- 50 degrees latitude
- HOW MUCH? 16 MT tons of water per crew
- WHEN? ISRU production in 480 days

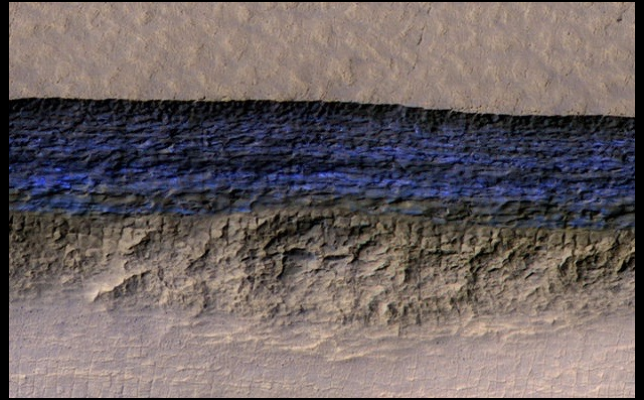


50° N

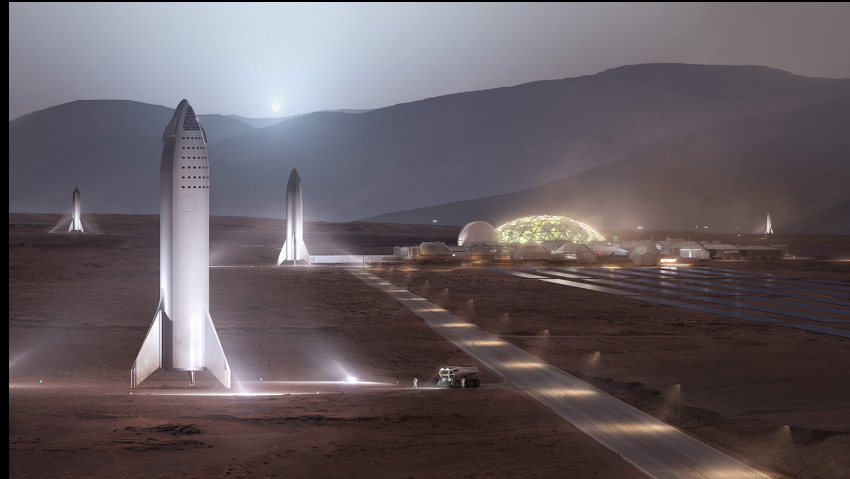
Potential source of water  
(SpaceX as customer):

SPACEX

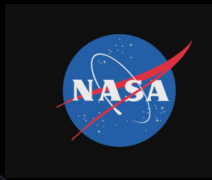
50° S



Subsurface ice



# #1 (The “Now”)

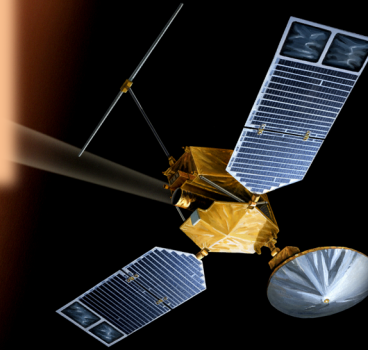


Mars Reconnaissance Orbiter (MRO)

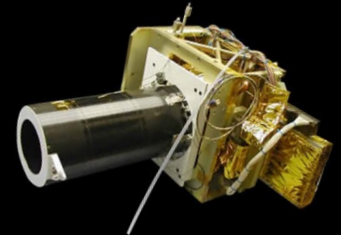
**SHARAD**  
(Shallow Radar)



**HiRISE, CTX Cameras**



**CRISM Spectrometer**



50° N



**Scientific contributions needed  
for resource identification that  
can serve several customers?**

**Answer: The three “Ns” ...**

50° S





# #2 (The “Next”)

50° N



50° S

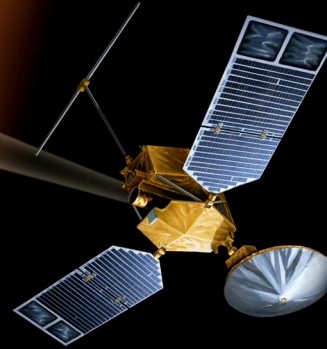


## NEW ORBITER

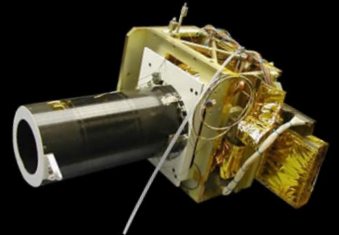
New Radar – SAR  
(High frequency,  
<1m depth resolution)



New Camera  
(higher resolution)



New Spectrometer  
(Hydrated Minerals)



# #3 (The “New”)

50° N

NASA

50° S

## SURFACE EXPLORATION (Ground truth)

- 1) Depth, horizontal distribution, concentration, morphology of ice
- 2) Geotechnical properties of regolith
- 3) Topography: terrain slope, rocks
- 4) Mineral identification and composition
- 5) Increase resource certainty and determine extraction technology

# Important resources for the Moon depend on the customer (NASA, other space agencies, the private sector)

## Rare Earths:

Nd, La



O

Si

H<sub>2</sub>O

## Volatiles:

H, He, N, C

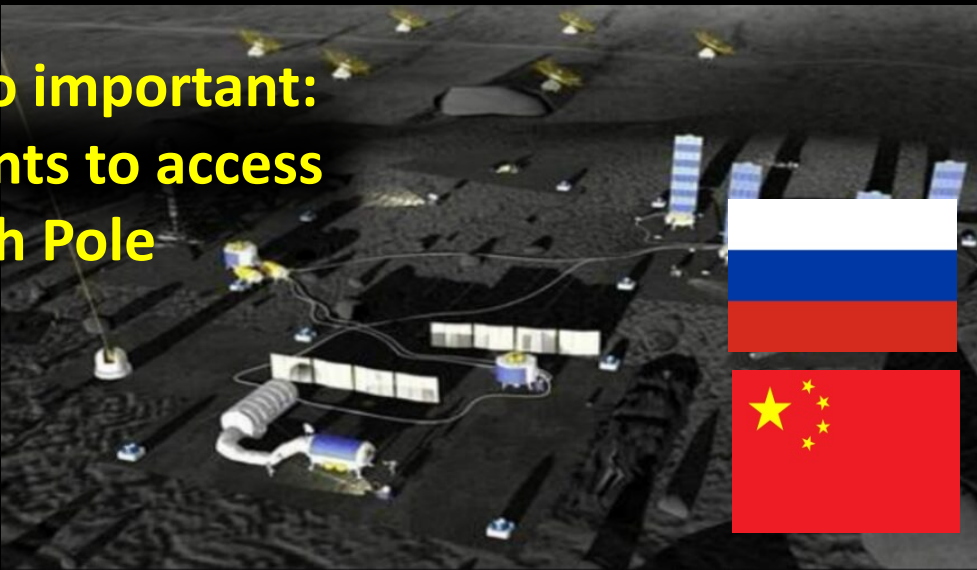
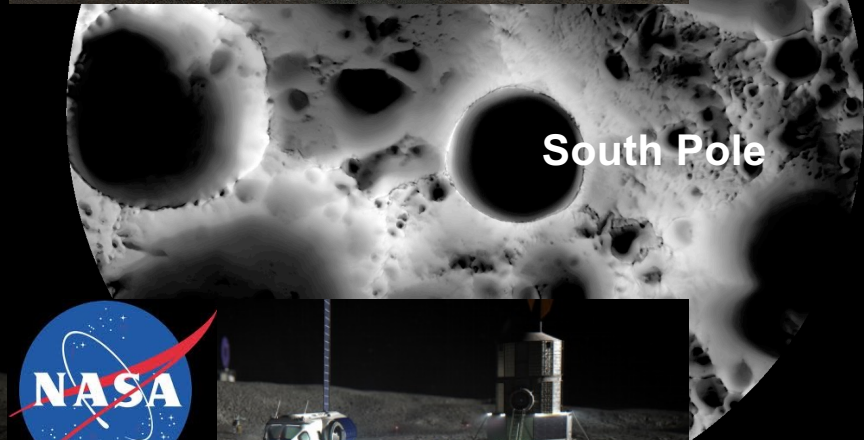
## Metals:

Fe, Ni, Mg, Ti, Al



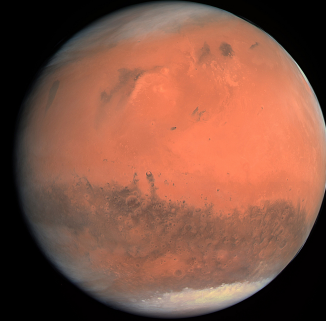
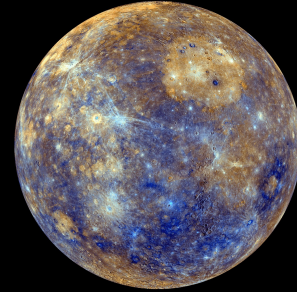
CLPS providers & other private companies

Location is also important:  
everybody wants to access  
the lunar South Pole



# Challenges and opportunities for the Decadal Survey

- Challenges: Many new factors and players to consider
- New opportunities not available to previous surveys:
  - More science
  - Faster results
  - Lower cost

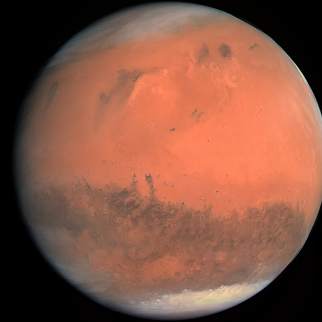
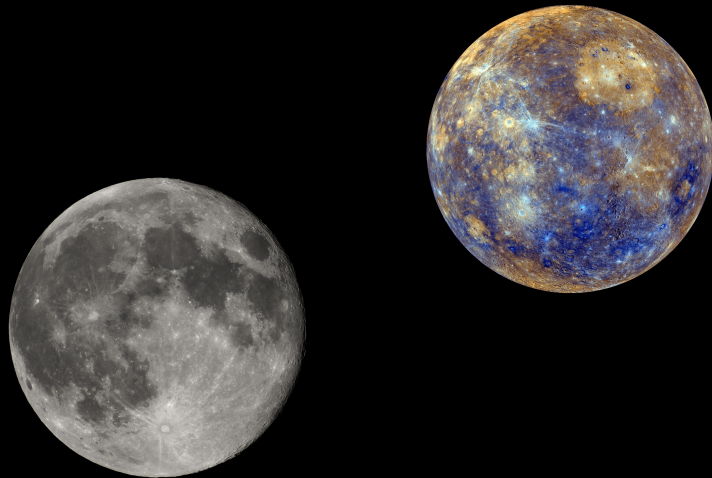


## Path forward:

- Collaboration & coordination are key
  - International cooperation
  - Public-private partnerships
  - Maximize science, exploration, and commercial interests

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