The Future of Lunar Exploration

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Outline

Two previous eras of lunar exploration
   “Space Race” era: Apollo, Luna
   Robotic era: 1990s – 2010s

Return to the Moon
   Polar volatiles and permanently shadowed regions
   Resources to “live off the land”

NASA’s Artemis Program
   Mandate for crewed landing in 2024
   Sustainable presence with international and commercial partners
   Learn to live & work off-world in preparation for missions to Mars
Apollo Lunar Exploration Program
What did the Apollo Missions Tell us?

• The Moon is old (~4.6 Ga)
• Moon moves away from Earth ~3 cm/yr
• Isotopic analysis shows Moon and Earth have crucial compositional similarities
• Early Moon was molten: magma ocean cooled to form the crust
  • Giant Impact Hypothesis
  • Earth was molten too!
• Impact cratering is an important geologic process – history preserved on the Moon
• Volcanic activity occurred ~4.2-3.16 Ga
Lunar exploration can reveal how the Earth-Moon system formed

Giant impact hypothesis for origin of Moon
The Late Heavy Bombardment (4.0 - 3.8 Ga)

We have reliable radiometric dates only for Imbrium and Orientale Basins
Setting the Solar System’s Clock

Ages of lunar surface samples calibrate the crater density “clock” used to estimate ages elsewhere on the Moon.

Also used to estimate ages of all other rocky-planetary surfaces in the Solar System despite major uncertainties.
Nice Model: Evolution of the Solar System

~4.2 Billion Years

~3.8 Billion Years

"Late Heavy Bombardment"

Today

Developing this model possible *only* by having lunar samples
Neutron spectro data: Inferred H concentrations
NASA's SLS and Orion - with our international partners.
Artemis I: First human spacecraft to the Moon

Artemis II: First humans to orbit the Moon

Artemis Support Mission: First high-power Solar Electric Propulsion module delivered

Artemis Support Mission: First pressurized module delivered

Artemis Support Mission: Human Landing System delivered

Artemis III: Crewed mission to Gateway and lunar surface

Commercial Lunar Payload Services - CLPS-delivered science and technology payloads

Early South Pole Mission(s) - First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site - First ground truth of polar crater volatiles

Large-Scale Cargo Lander - Increased capabilities for science and technology payloads

LUNAR SOUTH POLE TARGET SITE

2020

2024
Space For All

Unique moment for partnerships
Unlike “Space Race” era, robust international and commercial sectors
First steps in permanent human offworld presence

Everybody is needed
For every astronaut, maybe 20K people on the ground
All walks of life required!

A Generational Change
The “Artemis Generation” to succeed the “Apollo Generation”
Setting the stage for eventual human landings on Mars
Future Moon

Science & Exploration

Living off the Land

Multi-planet Species

Fuel Depot

Mining

Manufacturing
5-Hour Day
The Moon Stabilizes Our Spin Axis

- Slipping away 1 ½ inches per year
- Roche Limit
- 5 Hour Day
- Moon 4.5 Ga
- 10 Hour Day
- Moon 3.9 Ga
- 24 Hour Day
- Earth
- d ~ 21 Rₚ
- Moon Today
- d ~ 60 Rₚ
- 4.5 Ga
- 3.9 Ga
- Today
- Apparent Size
For every 1 impact on the Moon the Earth should have 20 impacts!
SWLunarInterior Radio Farside Water Cycle Chronology
Old Lunar Terrain Young Lunar Terrain

4.5 Ga

Giant Planet Migration

4.5 Ga

Solar Wind Plasma
Solar UV & X-rays

Primordial disk of icy bodies
Comets

Crust
Mantle
Core?
Magnetic Anomalies: Fe, Ni and PGM

- Platinum group metals (PGM) are primarily located in SPA Basin
- PGM concentration in iron meteorites can reach 200 ppm

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<th>PGM</th>
<th>Value per kg</th>
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<tr>
<td>Platinum</td>
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