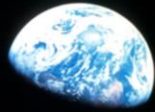


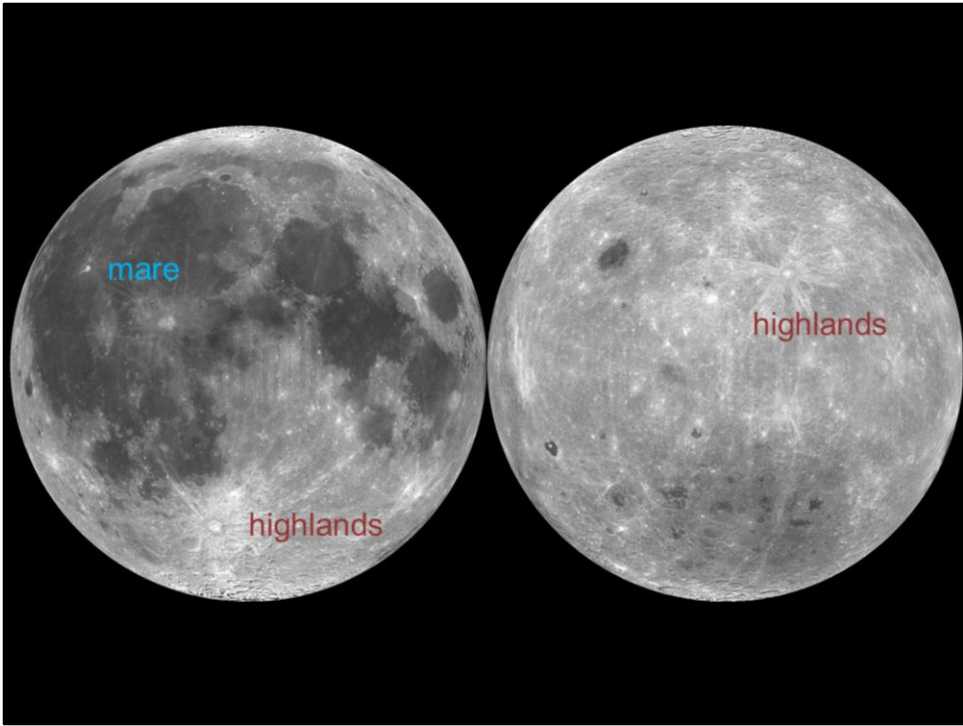
The Moon



Dr. Michael Zanetti
Lunar and Planetary Geologist – Marshall Space
Flight Center

Slides adapted from Dr. Sarah Noble - NASA Headquarters







Mare = Basalt

Mostly: Pyroxene $(\text{Fe}, \text{Mg})\text{Si}_2\text{O}_6$, Plagioclase $\text{Ca}(\text{Si}, \text{Al})_4\text{O}_8$,
Olivine $(\text{Mg}, \text{Fe})_2\text{SiO}_4$, Ilmenite FeTiO_3

Rare: Armalcolite

$(\text{Mg}, \text{Fe})\text{Ti}_2\text{O}_5$,

Tranquillityite

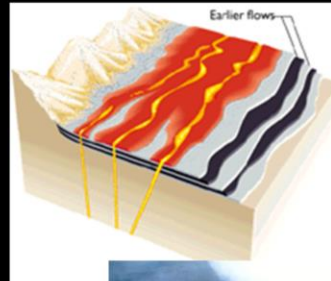
$\text{Fe}_8(\text{Zr}, \text{Y})_2\text{Ti}_3\text{Si}_3\text{O}_{24}$



Mare Volcanism



Mare Imbrium



Kilauea volcano, Hawaii, 1992

Volcanism *after* impacts – most before 3 (to 1) billion years ago

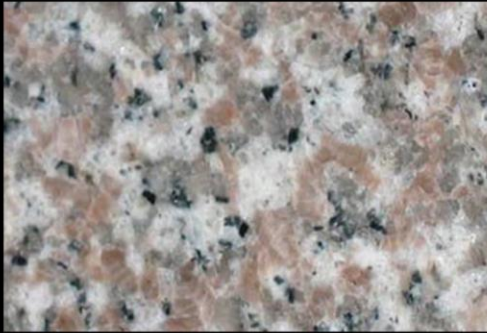
The deep parts of many large impact basins were later filled by eruptions of basaltic lava. This forms the circular Mare Imbrium (left image). At right, shadows reveal the edges of a long lava flow from the lower left to the upper right of the image. The volcanism in Mare Imbrium occurred about 3.3 billion years ago (7 am on our clock). Because of its small size, the Moon cooled quickly and was mostly dead volcanically by 3 billion years ago, although limited volcanism in isolated regions is thought to have occurred as recently as 1 to 2 billion years ago.

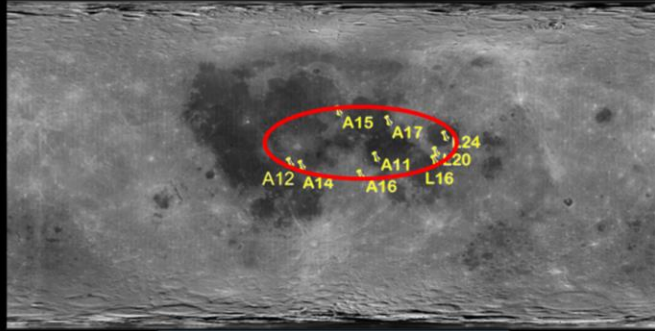
Lunar Volcanism

Portions of the Moon's interior remained hot enough to produce magma for more than a billion years after it formed. Molten rock flowed onto the lunar surface through cracks in the crust, spreading out and filling the low regions in the impact basins. The lava cooled quickly, forming the fine-grained, dark rocks — basalt — sampled during the Apollo missions. The dark areas seen on the Moon are basaltic lava plains 4.2 to 1 billion

(place at 3.5) Lunar volcanism decreased significantly by 3 billion years ago and ceased completely by about 1 billion years ago as the interior of this small body cooled. 3.0 Ga

Highlands =
Plagioclase Feldspar
 $\text{Ca}(\text{Si},\text{Al})_4\text{O}_8$

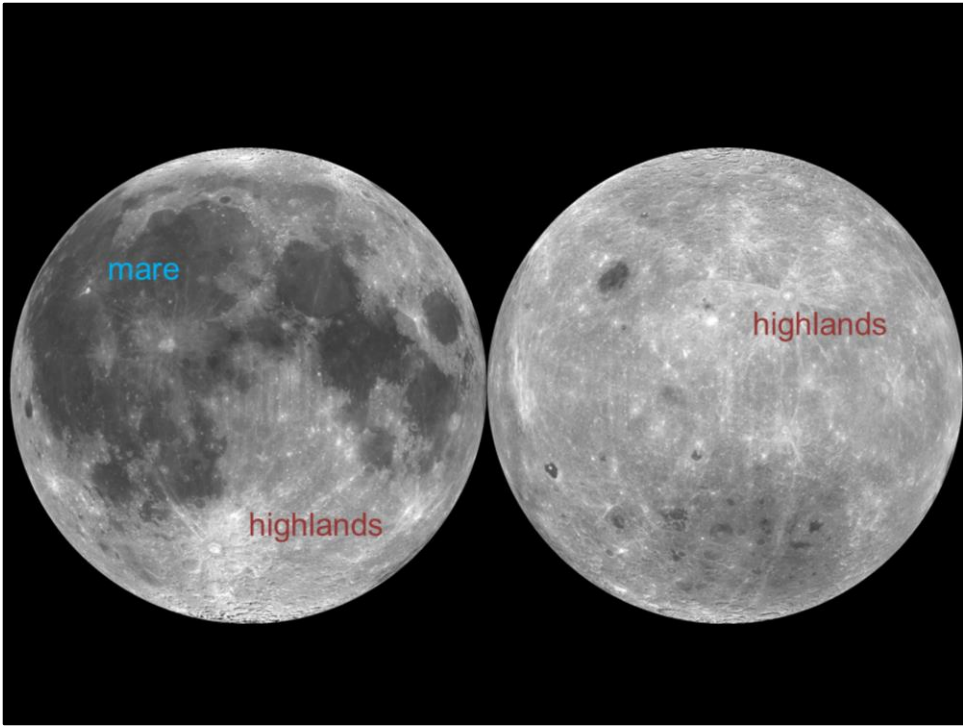




Apollo + Luna
sampling sites =
~6% of the total
lunar surface area

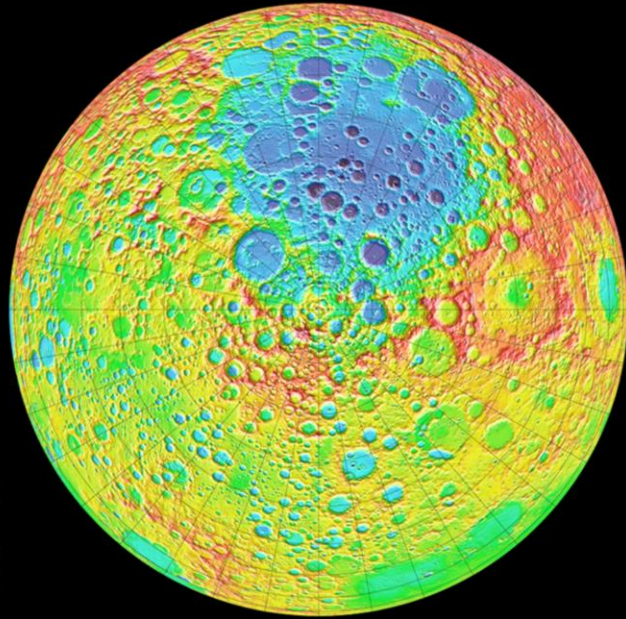


6% of the total
terrestrial surface
≈ North America



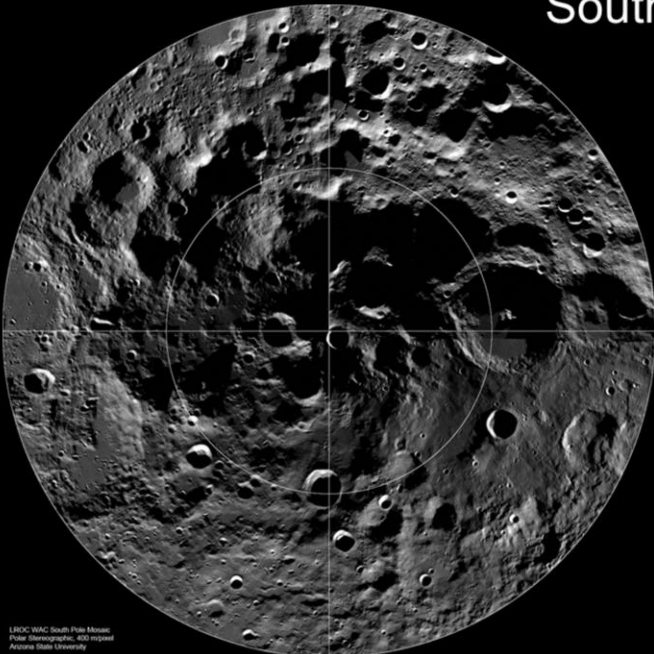
LOLA

South Pole



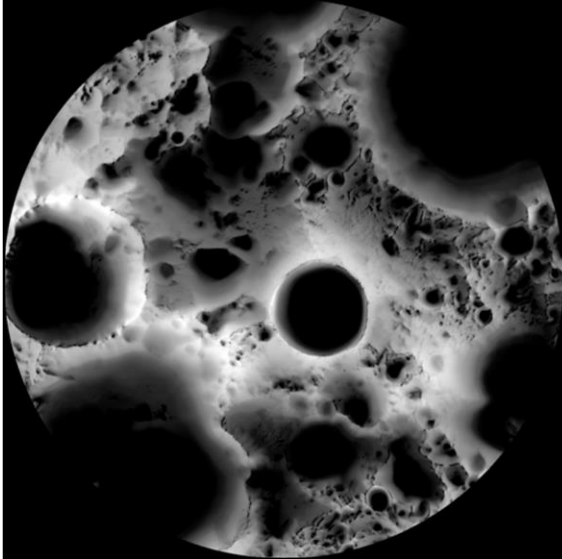
ALONG -TRACK SPACING
OF 60 M AND ACROSS-
TRACK SPACING OF 1/8
DEG (~4KM AT EQU)

South Pole



LROC WAC South Pole Moon
Polar Stereographic, 400° Inverted
Arizona State University

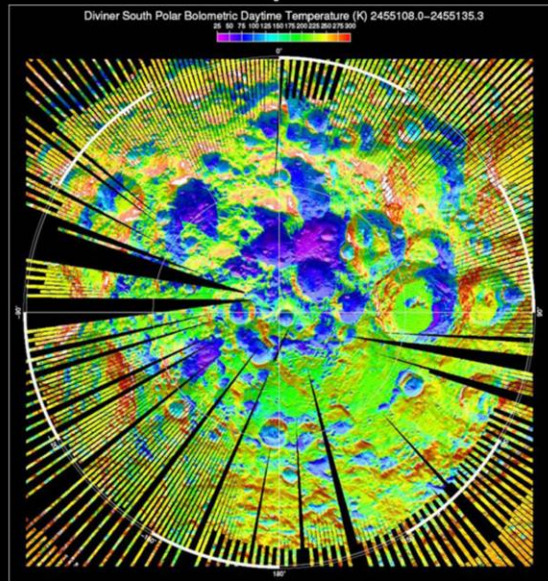
Light and Shadow

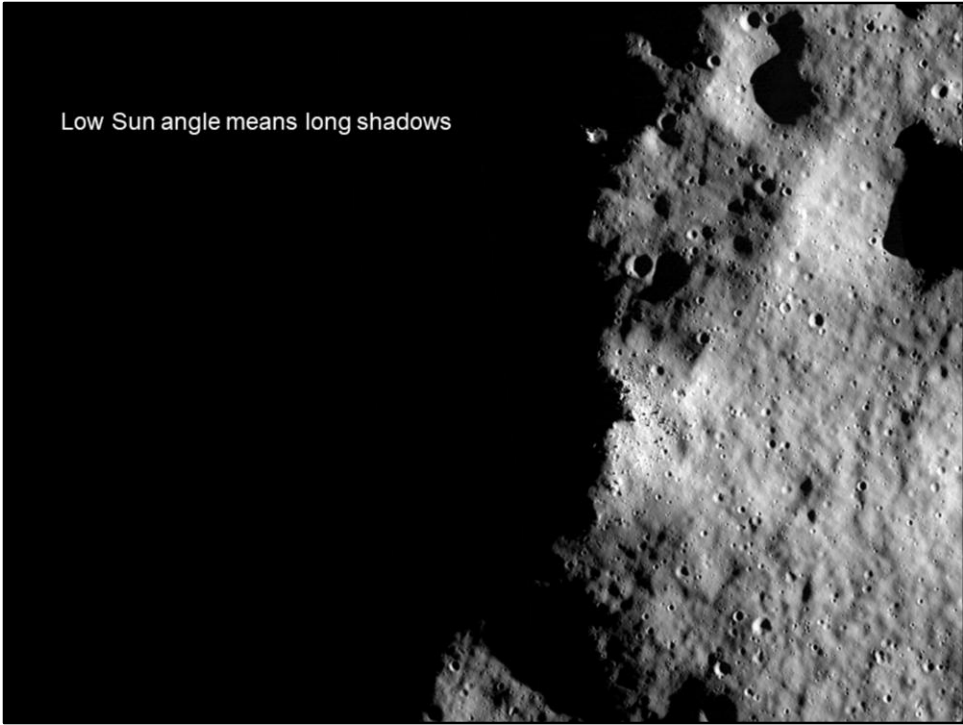


Illumination map
of the South
Pole compiled
over 6 months.

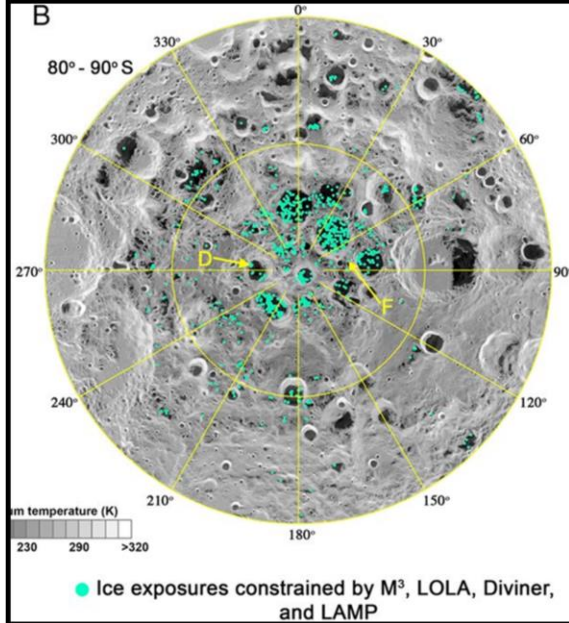
Brighter = more
days of sunlight,
Darker = more
days in shadow

DIVINER Temperature Map





Water at the Poles

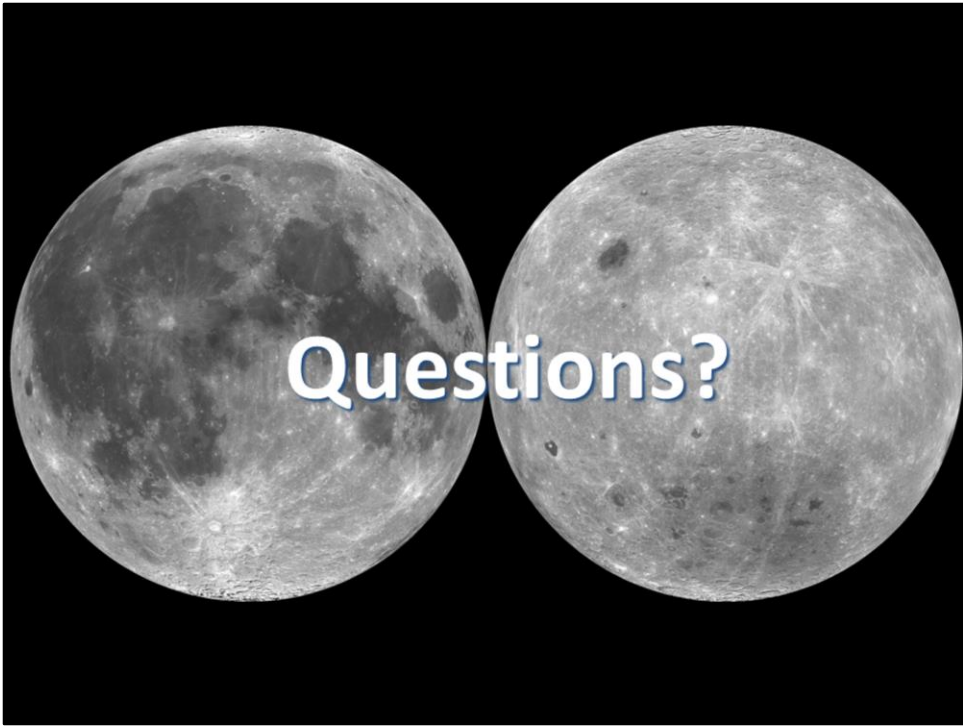


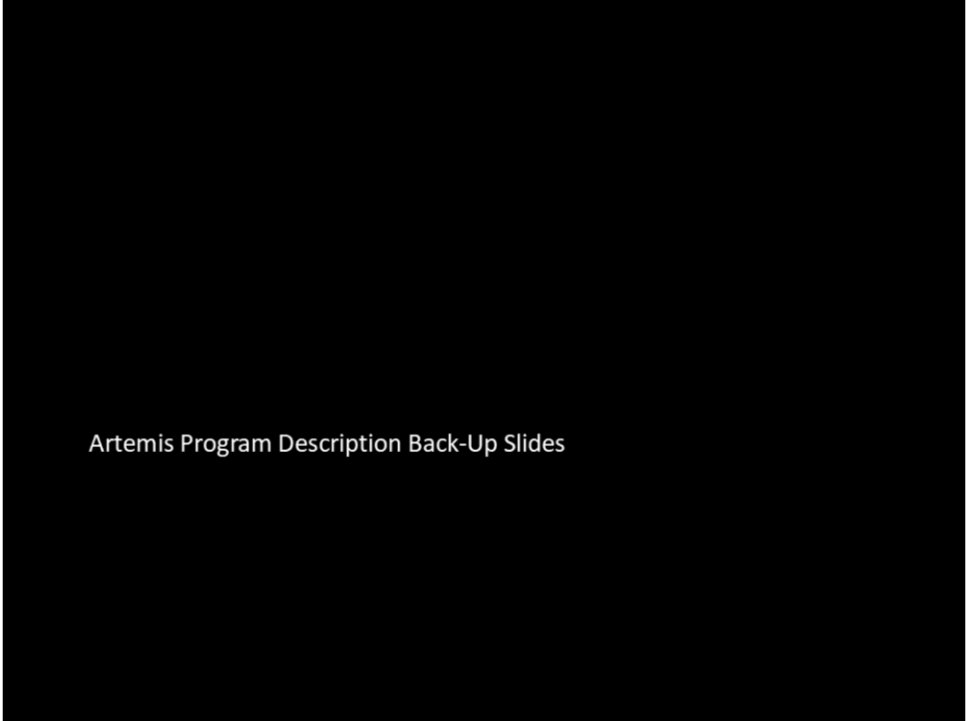
Direct evidence of surface exposed water ice in the lunar polar regions

Shuai et al, 2018

Big Science Questions

- Where are the polar volatiles and how did they get there?
 - What are the chemical and isotopic compositions of volatile deposits?
- How did the Moon form/evolve?
 - Sampling of ancient crust/mantle material, and geophysical measurements (seismometer/heat flow probe) will provide new insight into the lunar interior structure and composition, and of the Moon's geologic evolution
- Are there rock types that we didn't sample in Apollo, and what can they tell us about the Moon's evolution?
- Can we use the Moon to understand the distribution and timescale of impacts and volcanism on the inner planets?
- Can we explore craters to understand the physics of impact cratering, the most prevalent geologic process in the Solar System

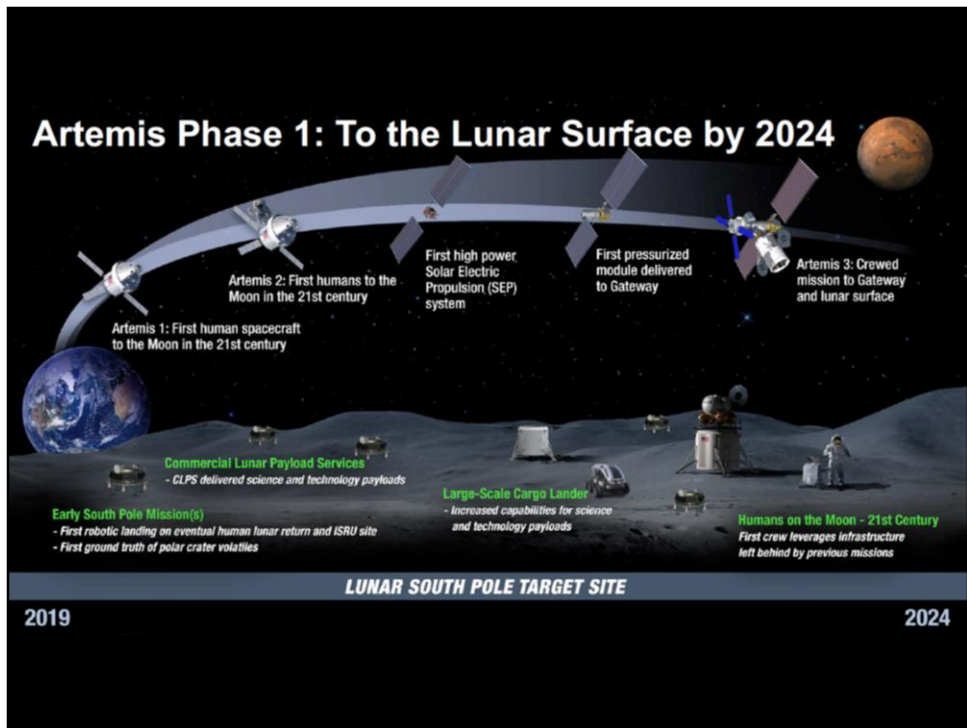




Artemis Program Description Back-Up Slides

Following slides taken from Administrator Bridenstein's presentation to the public on June 6, 2019.

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf



https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf

Achieving 2024 – A Parallel Path to Success

Artemis will see government and commercial systems moving in parallel to complete the architecture and deliver crew

CREW

NASA Programs SLS and Orion



Artemis 1

First flight test of SLS and Orion as an integrated system

Artemis 2

First flight of crew to the Moon aboard SLS and Orion

Artemis 3

First crew to the lunar surface; Logistics delivered for 2024 surface mission

Between now and 2024, U.S. industry delivers the launches and human landing system necessary for a faster return to the Moon and sustainability through Gateway.



Commercially Provided Elements

CARGO

PPE

Power Propulsion Element arrives at NRHO via commercial rocket

Pressurized Module

Small area for crew to check out systems prior to lunar transfer and decent

Human Landing System

Transfer

Transfers lander from Gateway to low lunar orbit

Descent

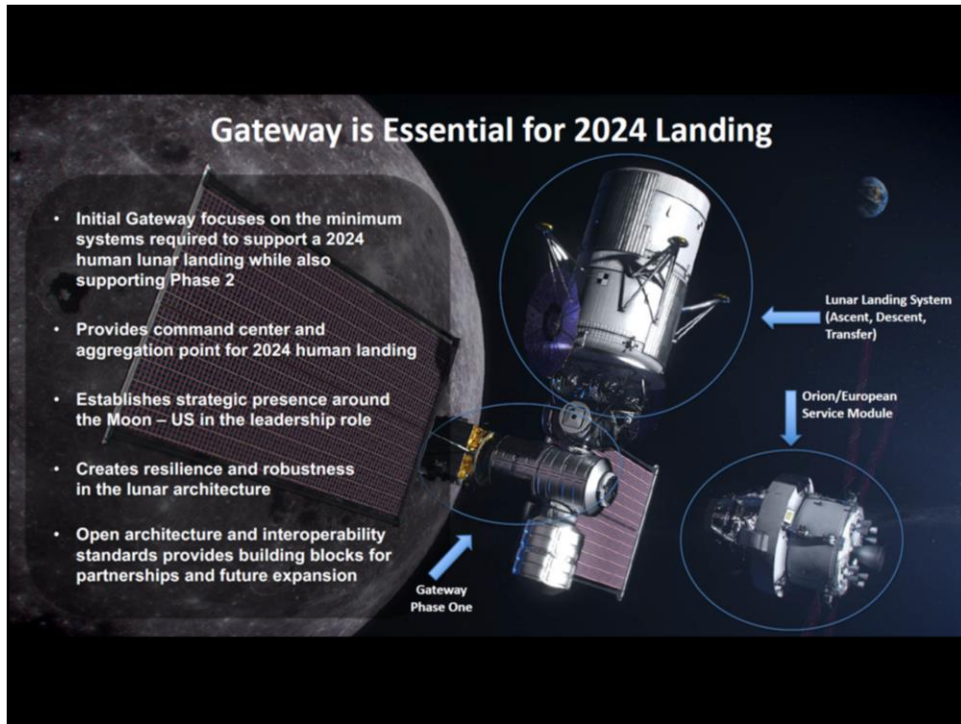
Descends from Transfer Vehicle to lunar surface

Ascent

Ascends from lunar surface to Gateway

Up to three commercial rocket launches, depending on distribution of the Transfer, Descent, and Ascent functions.

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf



https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_a_rtemis_20190523.pdf



Lunar Science by 2024

Polar Landers and Rovers

- First direct measurement of polar volatiles, improving understanding of lateral and vertical distribution, physical state, and chemical composition
- Provide geology of the South-Pole Aitken basin, largest impact in the solar system

Non-Polar Landers and Rovers

- Explore scientifically valuable terrains not investigated by Apollo, including landing at a lunar swirl and making first surface magnetic measurement
- Using PI-led instruments to generate Discovery-class science, like establishing a geophysical network and visiting a lunar volcanic region to understand volcanic evolution

Orbital Data

- Deploy multiple CubeSats with Artemis 1
- Potential to acquire new scientifically valuable datasets through CubeSats delivered by CLPS providers or comm/relay spacecraft
- Global mineral mapping, including resource identification, global elemental maps, and improved volatile mapping

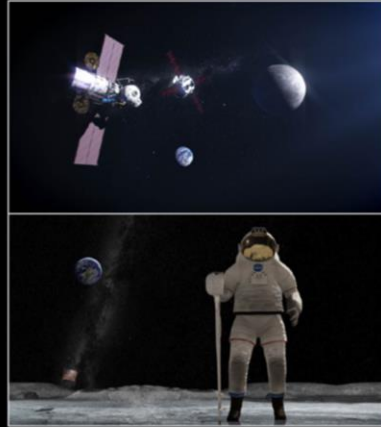
In-Situ Resource Initial Research

- Answering questions on composition and ability to use lunar ice for sustinment and fuel

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_artemis_20190523.pdf

Sustainability at the Moon and on to Mars

- The U.S. leading in exploration and setting the standards for the Moon
- Unbound potential for partnerships and collaboration
- Meaningful, long-duration human missions
- Testing impacts on human performance and exploration operations to be used for Mars
- Repeatable operations traveling from Earth to the Gateway to the surface with reusable systems
- Unprecedented science outside of Earth's influence
- Maintains strategic presence as a deep space port and refueling depot around the Moon
- Increases international and commercial partnership opportunities, fostering healthy competition



https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_a_rtemis_20190523.pdf

A black and white photograph of a lunar surface. In the foreground, a coiled spring and a probe are visible, likely part of a lunar lander or rover. The background shows the dark, cratered surface of the moon.

Science After 2024

Human and Robotic Missions Provide Unique Science Opportunities

On Gateway

- Deep space testing of Mars-forward systems
- Hosts groundbreaking science for space weather forecasting, full-disc Earth observation, astrophysics, heliophysics, lunar and planetary science
- Mars transit testbed for reducing risk to humans

Surface Exploration

- Understanding how to use in-situ resources for fuel and life
- Revolutionizing the understanding of the origin and evolution of the Moon and inner solar system by conducting geophysical measurements and returning carefully selected samples to Earth
- Studying lunar impact craters to understand physics of the most prevalent geologic process in the solar system, impact cratering
- Setting up complex surface instrumentation for astrophysics, heliophysics and Earth observation
- Informing and supporting sustained human presence through partial gravity research in physical and life sciences, from combustion to plant growth

Surface Telerobotics to Provide Constant Science

- Sending rovers into areas too difficult for humans to explore; rovers can be teleoperated from Earth to maximize the scientific return

https://www.nasa.gov/sites/default/files/atoms/files/america_to_the_moon_2024_a_rtemis_20190523.pdf