ARTEMIS SCIENCE

Jacob Bleacher, Ph.D.
Chief Exploration Scientist
Exploration Systems Development Mission Directorate
“The United States will Maintain its Leadership in Space Exploration and Space Science”

“Remain a global leader in science and engineering by pioneering space research and technology that propels exploration of the Moon, Mars, and beyond.”

“U.S. human and robotic space exploration missions will land the first woman and person of color on the Moon, advance a robust cis-lunar ecosystem, continue to leverage human presence in low-Earth orbit to enable people to live and work safely in space, and prepare for future missions to Mars and beyond.”

— The White House U.S Space Priorities Framework, Dec 2021

United States Space Priorities Framework
NASA 2022 Strategic Plan
2023 NASA Budget Request
NASA’s Moon to Mars Objectives
A blueprint for future human exploration

**SCIENCE**
Conduct science on and around the Moon, using humans and robots to address scientific priorities about the Moon. Demonstrate future science methods astronauts can use beyond Low Earth Orbit:
- Lunar/Planetary
- Heliophysics
- Biological/Physical
- Astrophysics

**TRANSPORTATION AND HABITATION**
Develop and demonstrate an integrated system to conduct human missions. Live and work at deep space destinations and safely return to Earth.

**LUNAR AND MARS INFRASTRUCTURE**
Maintain continuous robotic and human presence on the Moon with multiple international and industry users to develop a robust lunar economy. Create infrastructure to support initial human Mars demonstration and to continue exploring the solar system.

**OPERATIONS**
Conduct human missions on and around the Moon followed by missions to Mars. Use a gradual approach to build, demonstrate, and operate new technologies to live and work on other planetary bodies.

Requested feedback on these objectives in summer 2022 from the following key stakeholders:
- NASA workforce: our greatest asset
- International partners: our key current and future, anticipated collaborators
- U.S. industry, academia, DOE, NIH, NSF, etc.: our national leaders in space research and capabilities
Artemis Science Objectives

• Understand planetary processes
• Understand the character and origin of lunar polar volatiles
• Interpret impact history of Earth-Moon system
• Reveal the record of the ancient sun and our astronomical environment
• Observe the universe and the local space environment from a unique location
• Conduct experimental science in the lunar environment
• Investigate and mitigate exploration risks

Pictured left: NASA astronaut candidates and field instructors hike during geology training in Arizona
Artemis Technology Objectives

The Lunar Surface Innovation Initiative (LSII) works across industry, academia and government through in-house efforts and public-private partnerships to develop transformative capabilities like:

- In-situ resource utilization (ISRU)
- Surface power
- Dust mitigation
- Extreme environment
- Extreme access
- Excavation and construction

**Pictured left:** A Honeybee Robotics systems engineer installs The Regolith and Ice Drill for Exploring New Terrain (TRIDENT) on a trolley for thermal vacuum chamber testing. TRIDENT will drill up to three feet deep, extracting lunar soil and demonstrating a critical capability for future ISRU.
Hazards of Human Spaceflight

1. Space Radiation
   Invisible to the human eye, radiation increases cancer risk, damages the central nervous system, and can alter cognitive function, reduce motor function and prompt behavioral changes.

2. Isolation and Confinement
   Sleep loss, circadian desynchronisation, and work overload may lead to performance reductions, adverse health outcomes, and compromised mission objectives.

3. Distance from Earth
   Planning and self-sufficiency are essential keys to a successful mission. Communication delays, the possibility of equipment failures and medical emergencies are some situations the astronauts must be capable of confronting.

4. Gravity (or lack thereof)
   Astronauts encounter a variance of gravity during missions. On Mars, astronauts would need to live and work in three-eighths of Earth’s gravitational pull for up to two years.

5. Hostile/Closed Environments
   The ecosystem inside a vehicle plays a big role in everyday astronaut life. Important habitability factors include temperature, pressure, lighting, noise, and quantity of space. It’s essential that astronauts stay healthy and happy in such an environment.
ESDMD/SOMD Directorate-level Technical Documentation – Current and Planned

- NASA Authorization Act
- NASA Strategic Plan

**Utilization Plan**
- Science and Technology Utilization goals, objectives, capabilities, and mission-specific requirements
  - HEOMD-006

**Strategic Campaign Operations Plan for Exploration (SCOPE)**
- High level overview of the campaign
  - HEOMD-007

**Configuration Management Process**
- HEOMD-002

**Crewed Deep Space Systems Human Rating Certification Requirements and Standards for NASA Missions**
- HEOMD-003

**International Interoperability Standards**
- Avionics, communications, ECLSS, power, rendezvous, external robotics, thermal, software
  - HEOMD-003-01-08

**Requirements**
  - HEOMD-004

**Utilization Plan**
- Science and Technology Utilization goals, objectives, capabilities, and mission-specific requirements
  - HEOMD-006

**Strategic Campaign Implementation Plan (SIP)**
- HEOMD-008

**Risk Management Plan (RMP)**
- HEOMD-008-01

**Engineering Management Plan (EMP)**
- HEOMD-009

**Cross-Directorate/Enterprise/Program Concept of Operations, Requirements, Standards**

- ACD Requirements
- CESD Requirements
- SCAm Requirements

- Program System Requirements Documents
INTEGRATING ACROSS MISSION DIRECTORATES
Integrate science and technology goals from mission directorates and international partners to develop HEO utilization goals, objectives and requirements for Artemis missions, and the cross-platform research strategy to prepare for human missions to Mars.

EXAMPLES:
- HEO-006 Utilization Plan joint with SMD and STMD - High level utilization goals, objectives and requirements
  - Utilization capabilities and their phasing over time
  - Mission-specific annexes with mission directorate requirements to enable research solicitations
  - Includes ISS, Commercial LEO, Artemis and Mars
- Co-chair the Utilization Coordination and Integration Working Group (UCIG) with SMD & STMD
- Coordinating HEO process for using our CLPS mass allocations and representative to SMD CLPS manifest selection board

INTEGRATING WITH HEO DIVISIONS
- Work with divisions and users on high-level goals, objectives, and strategic plans
- Interface with AES and ESD on approach to implementation and payload manifest for Artemis
- Ensure science and technology inputs are integrated into Exploration formulation activities

UTILIZATION COORDINATION AND INTEGRATION WORKING GROUP (UCIG) REQUIREMENTS FLOW

- Mission Directorate Representatives that fund utilization
  - SMD/ESSIO
  - SMD/BPSD
  - SMD/DAA Programs
  - STMD
  - HEO/HMD
  - HEO/HMD/AES Enabling Capabilities
  - Office of Planetary Protection

- HEO Representatives
  - Science & Technology Utilization (SEI)
  - Other SEI Orgs

- Implementing Divisions
  - ESD
  - AES
  - HSFC
  - ISS
  - CSD
  - SCaN

- Observers
  - Office of the Chief Scientist
  - Office of the Chief Technologist
  - Office of International and Interagency Relations
  - Technical Authorities

- Implementing Programs
  - Gateway
  - HLS
  - LTV
  - ISS

Requirements Flow
Identifies and describes NASA's science and technology utilization goals and objectives that will be enabled by human missions.

Authority Quad-Directorate:
• Science Mission Directorate (SMD),
• Space Technology Mission Directorate (STMD),
• Space Operations Mission Directorate (SOMD)
• Exploration Systems Development Mission Directorate (ESDMD)

Purpose:
Identify how human missions will support the science and technology communities to conduct fundamental research about our universe and solve the scientific and technological challenges for sustaining and expanding human exploration

Scope: Utilization of ISS/LEO, Artemis, Mars

https://ntrs.nasa.gov/citations/20220005087
# Utilization Plan

## Main Body Goals By NASA Directorate

Goals and Objectives are owned by each mission directorate and updated as needed (e.g., Decadal Survey inputs, Agency Strategic Planning, etc.)

<table>
<thead>
<tr>
<th>Mission Directorate</th>
<th>Utilization Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3.1 SMD</strong></td>
<td></td>
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<tr>
<td>SMD Utilization Goal 1</td>
<td>Enable scientific investigations from the lunar surface, including field relationships, in-situ observations, and sample return, to address the multidisciplinary objectives of the Science Mission Directorate</td>
</tr>
<tr>
<td>SMD Utilization Goal 2</td>
<td>Enable scientific investigations from human spaceflight platforms to address the multidisciplinary objectives of the Science Mission Directorate</td>
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<tr>
<td>SMD Utilization Goal 3</td>
<td>Enable science investigations on the surface of Mars, in Mars orbit, and in Mars transit</td>
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<tr>
<td><strong>3.2 STMD</strong></td>
<td></td>
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<tr>
<td>STMD Utilization Goal 1</td>
<td>Enable sustainable living and working farther from Earth (“Live”)</td>
</tr>
<tr>
<td>STMD Utilization Goal 2</td>
<td>Enable transformative missions and discoveries (“Explore”)</td>
</tr>
<tr>
<td><strong>3.3 ESDMD / SOMD</strong></td>
<td></td>
</tr>
<tr>
<td>ESDMD/SOMD Utilization Goal 1</td>
<td>Advance knowledge to support safe, productive human space travel, and enable systems development and testing to reduce health and performance risks for future human exploration</td>
</tr>
<tr>
<td>ESDMD/SOMD Utilization Goal 2</td>
<td>Advance the operational capabilities required for sustainable lunar operations and the first human missions to Mars including demonstrating approaches to planetary protection.</td>
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<tr>
<td><strong>3.4 NASA Multi-directorate</strong></td>
<td></td>
</tr>
<tr>
<td>Multi-directorate Utilization Goal 1</td>
<td>Enable commercial, interagency, and international partnerships to make space exploration more affordable and sustainable, grow new markets, and increase capabilities</td>
</tr>
</tbody>
</table>
HEOMD-006 Utilization Plan
Annex 1: Cornerstone Capabilities that Enable Multiple Objectives

1.1 MODEL TRAVERSE APPROACHES
1.2 END-TO-END SAMPLE RETURN
1.3 INTEGRATED PLANETARY PROTECTION STRATEGY
1.4 EXTENDED MISSIONS
1.5 INTEGRATED CREW RESEARCH
1.6 ROBOTIC UTILIZATION FOR HEO ASSETS
1.7 INTEGRATED INSTRUMENT STRATEGY
1.8 OPERATIONS IN COLD & SHADOWED REGIONS
Artemis: A Foundation for Deep Space Exploration

- Space Launch System
- Orion spacecraft
- Human Landing System
- Surface Operations
- Gateway
- Exploration Ground Systems
- Space Communications & Navigation
- Surface Mobility
- Spacesuits
- Artemis Base Camp
ARTEMIS I
The First Uncrewed Integrated Flight Test of NASA’s Orion Spacecraft and Space Launch System Rocket

1. LAUNCH
SLS and Orion lift off from pad 39B at Kennedy Space Center.

2. PERIGEE RAISE MANEUVER
Systems check with solar panel adjustments.

3. EARTH ORBIT
Ittle (TIL) BURN
Maneuver lasts for approximately 20 minutes.

4. INTERIM CRYOGENIC PROPULSION STAGE (ICPS) SEPARATION AND DISPOSAL
ICPS commits Orion to moon at TLI.

5. OUTBOUND POWERED FLYBY (OPF)
60 nmi from the Moon; targets DRO insertion.

6. LUNAR ORBIT INSERTION
Enter Distant Retrograde Orbit.

7. OUTBOUND TRAJECTORY CORRECTION (OTC) BURNS
As necessary adjust trajectory for lunar flyby to Distant Retrograde Orbit (DRO).

8. DISTANT RETROGRADE ORBIT
Perform half or one and a half revolutions in the orbit period 38,000 nmi from the surface of the Moon.

9. DRO DEPARTURE
Leave DRO and start return to Earth.

10. RETURN POWERED FLYBY (RPF)
RPF burn prep and return coast to Earth initiated.

11. RETURN TRANSIT
Return Trajectory Correction (RTC) burns as necessary to aim for Earth’s atmosphere.

12. SPLASHDOWN
Pacific Ocean landing within view of the U.S. Navy recovery ship.

13. CREW MODULE SEPARATION FROM SERVICE MODULE

14. ENTRY INTERFACE (EI)
Enter Earth’s atmosphere.

15. CUBESATS DEPLOY
ICPS deploys 10 CubeSats total

MISSION DURATIONS:
Total: 26–42 days
Outbound Transit: 8–16 days
DRO: 6–19 days
Return Transit: 9–19 days
**Artemis I CubeSat Payloads**

*Science and technology investigations and demonstrations paving the way for future, deep space human exploration*

**ArgoMoon**
Photograph the Interim Cryogenic Propulsion Stage (ICPS) CubeSat deployment, the Earth and Moon using HD cameras and advanced imaging software.

**OMOTENASHI**
Develop world's smallest lunar lander and observe lunar radiation environment.

**LunIR**
Use a miniature high-temperature Mid-Wave Infrared (MWIR) sensor to characterize the lunar surface.

**LunaH-Map**
Perform neutron spectroscopy to characterize abundance of hydrogen in permanently shaded craters.

**Lunar IceCube**
Search for water (and other volatiles) in ice, liquid and vapor states using infrared spectrometer.

**Team Miles**
Demonstrate propulsion using plasma thrusters; compete in NASA’s Deep Space Derby.

**Near-Earth Asteroid Scout (NEA Scout)**
Detect target NEA, perform reconnaissance and close proximity imaging.

**BioSentinel**
Use yeast as a biosensor to evaluate the effects of ambient space radiation on DNA.

**CubeSat to Study Solar Particles (CuSP)**
Measure incoming radiation that can create a wide variety of effects on Earth.

**EQUULEUS**
Demonstrate trajectory control techniques within the Sun-Earth-Moon region and image Earth’s plasmasphere.

**INTERNATIONAL COLLABORATION**
Artemis I Pressurized Payloads

Payloads that will fly inside of the Orion crew module

There will be three types of sensors, including the ESA Active Dosimeters, Hybrid Electronic Radiation Assessor (HERA), and the Radiation Area Monitor (RAM).

Demonstrate voice activated virtual assistant which enables hands free crew interface. Evaluate effectiveness of on board vs. ground supported crew assisted capabilities.

Investigation with DLR and ISA for to evaluation radiation protection vest for astronauts.

A battery-powered life sciences payload for biology research beyond low-Earth orbit (LEO). May be as many as four investigations.
LUNAR MISSIONS
2021–2025

NASA CLPS DELIVERY GOALS

PEREGRINE-1
- Regolith volatiles composition
- Local radiation environment

1ST NOVA-C
- Plume/surface interactions, charged particles near surface
- Lander prop tank gauge test

2ND NOVA-C
- Drilling for volatiles

GRIFFIN-1 & VIPER
- Search for volatiles, below surface and in shadowed regions

BLUE GHOST
- Characterize Earth’s magnetosphere and Moon’s interior

XL-1
- Regolith volatiles composition
- Surface terrain & mineralogy

CP-11
- Lunar Magnetic Anomalies

DRAPER
- Geophysics of the Schrödinger Basin

KEY
- CLPS DELIVERY
- INTERNATIONAL LED
- HUMAN EXPLORATION
- SCIENCE
- SPACE TECHNOLOGY

11.29.2021
The Solar System Exploration Research Virtual Institute (SSERVI) supports human exploration and scientific discovery by integrating interdisciplinary research to prioritize and resolve key knowledge gaps.

Key Exploration Science Events:
- **NASA Exploration Science Forum (NESF):** Virtual/In-person conference featuring scientific discussions about the Moon and other exploration targets of interest. All past Forum recordings and archives available at sservi.nasa.gov
- **European Lunar Symposium (ELS):** Annual meeting that brings together the U.S. and European lunar science, exploration, and launch communities. ELS documents and video archives: https://els2020.arc.nasa.gov/
- **Solar System Treks Project (SSTP):** A free, web-based application that provides high-resolution images and visualizations of planetary bodies using real spacecraft data. Provides mission planning data analyses to domestic and international lunar missions. New portals and updates released in support of upcoming missions. Access all Trek portals at https://trek.nasa.gov

**SSERVI at a Glance:**
Jointly funded by NASA HEOMD and SMD, SSERVI is focused on science enabling human exploration and science enabled by human exploration. Currently **12 Overlapping U.S. Teams** funded in 2017 and 2019, each with 5-year cooperative agreements. **1000+ publications** since SSERVI started in 2013. Many additional conference publications and other scientific products.

Management of the **Solar System Treks Project (SSTP),** a visualization tool originally created during Constellation program, at request of NASA HQ. **11 Int’l partners** with a focus on lunar science and missions:

Australia, Canada, France, Germany, Israel, Italy, Japan, Korea, the Netherlands, Saudi Arabia, United Kingdom
Initial Gateway Science Payloads

Gateway’s orbit will offer unique opportunities for heliophysics, human health research, space biology and life sciences, astrophysics, and fundamental physics investigations. As new modules are added, science capability will increase.

Heliophysics Environmental Radiation Measurement Experiment Suite (HERMES): NASA’s space weather instrument suite will observe lower energy solar particles critical to scientific investigations of the Sun including the solar winds

European Radiation Sensors Array (ERSA): The European Space Agency’s (ESA) radiation instrument package will help provide an understanding of how to keep astronauts safe by monitoring the radiation at higher energies with a focus on space weather

ESA’s Internal Dosimeter Array (IDA): Instruments including those provided by Japan Aerospace Exploration Agency (JAXA) will inform for improvements in radiation physics models for cancer, cardiovascular, and central nervous system effects, helping assess crew risk on exploration missions