All elements needed for a human Mars mission are in development now.

**EARTH RELIANT**

Now - Mid-2020s

- International Space Station operation through 2024
- Commercial development of low-Earth orbit
- Development of deep space systems, life support, and human health

**PROVING GROUND**

2018 - 2030

- Regular crewed missions and spacewalks in cis-lunar space
- Verify deep space habitation and conduct a yearlong mission to validate readiness for Mars
- Demonstrate integrated human and robotic operations by redirecting and sampling an asteroid boulder

**EARTH INDEPENDENT**

Now - 2030s & Beyond

- Science missions pave the way to Mars
- Demonstrate entry, descent, and landing and in-situ resource use
- Conduct robotic roundtrip demonstration with sample return in the late 2020s
- Send humans to orbit Mars in the early 2030s
Strategic Principles for Sustainable Exploration

- **FISCAL REALISM**: Implementable in the *near-term with the buying power of current budgets* and in the longer term with budgets commensurate with economic growth;

- **SCIENTIFIC EXPLORATION**: *Exploration enables science and science enables exploration*; leveraging scientific expertise for human exploration of the solar system.

- **TECHNOLOGY PULL AND PUSH**: Application of high Technology Readiness Level (TRL) technologies for near term missions, while focusing sustained investments on *technologies and capabilities* to address the challenges of future missions;

- **GRADUAL BUILD UP OF CAPABILITY**: *Near-term mission opportunities* with a defined cadence of compelling and integrated human and robotic missions, providing for an incremental buildup of capabilities for more complex missions over time;

- **ECONOMIC OPPORTUNITY**: Opportunities for *U.S. commercial business* to further enhance their experience and business base;

- **ARCHITECTURE OPENNESS AND RESILIENCE**: Resilient architecture featuring multi-use, evolvable space infrastructure, minimizing unique developments, with each mission leaving something behind to support subsequent missions;

- **GLOBAL COLLABORATION AND LEADERSHIP**: Substantial *new international and commercial partnerships*, leveraging current International Space Station partnerships and building new cooperative ventures for exploration; and

- **CONTINUITY OF HUMAN SPACEFLIGHT**: *Uninterrupted expansion of human presence into the solar system* by establishing a regular cadence of crewed missions to cislunar space during ISS lifetime.
Human Space Exploration Phases
From ISS to the Surface of Mars

Today

Phase 0: Exploration Systems
*Testing on ISS*

Phase 1: Cislunar Flight
*Testing* of Exploration Systems

Phase 2: Cislunar Validation
of Exploration Capability

Phase 3: Crewed Missions
Beyond Earth-Moon System

Phase 4a: Development
and robotic preparatory missions

Phase 4b: Mars
Human Landing Missions

Planning for the details and specific objectives will be needed in ~2020

* There are several other considerations for
ISS end-of-mission*

Easts with testing, research and demos complete*

Asteroid Redirect-Crewed Mission Marks Move from Phase 1 to Phase 2

Ends with one year crewed Mars-class shakedown cruise

Mid-2020s 2030
HEOMD Exploration Strategic Objectives

• NASA is defining a set of near term missions which build capabilities necessary to plan more challenging missions. This steady progression along with phased hardware development ultimately will yield a capability to take humans to the vicinity of Mars in the early 2030s.

• We are working toward a year-long “validation” cruise in cislunar space that will validate readiness to explore beyond the Earth-Moon system in the late 2020s

• All of the basic hardware needed to operate in the proving ground and support transit flights to Mars is in some stage of development now.
  – Commercial cargo and crew for access to ISS-LEO private sector demand
  – SLS and Orion (SLS evolves thru block upgrades beginning with EUS)
  – Launch site infrastructure to support both NASA and commercial missions
  – ARM with SEP for in-space propulsion (evolvable to a Mars-class capability)
  – Deep space habitation (Basis for Mars transit hab)

• NASA has baselined the Phase 0/1/2 Objectives (see back-up )
• NASA is focusing studies to determine and select architectures and technology for phase 3 and 4 (Mars sample return and Human landing and return)
HEO Exploration Objectives

- Journey to Mars narrative and Phase Goals defined in the NASA Journey to Mars Report
- Previously documented Phase Goals rolled into the Phase Objectives as appropriate
- Cross cutting Objective Categories provide continuity among Phases
- Future effort to align Phase Objectives with the FTO’s
HEO Exploration Tactical Mission capability Development – Test objectives

- The next step is to allocate Phase Objectives to flight objectives for EM-2 through 8; this work will be conducted in 2017-20

- Progress to date (see back up for details):
  - EM-1 well-defined: first test of integrated of integrated SLS/Orion stack; DRO around the moon; deploy 13 Cubesats (selected)
  - EM-2: first flight of SLS/Orion with crew and Exploration upper Stage; flight profile baselined as a multi-trans-lunar injection (MTLI) with a lunar fly-by free return trajectory.
  - Working toward 1 flight/yr cadence after EM-2; start of this cadence depends on FY17 appropriations and program performance
  - Initial cis-lunar habitation capability in early 2020s, depending on outcome of NextSTEP activity, and international planning/contributions
  - Asteroid Redirect Crewed Mission in ~2026
  - Build up of cis-lunar habitation/logistics capability in mid/late 2020s leading to one-year shakedown cruise in 2029 with Mars deep space transport vehicle

- NASA is aware of timing constraints and developing missions and baselining technologies as needed. This approach allows for new capabilities and provides resiliency in a chaotic environment.

- HEO, SMD, and STMD are collaborating on technology developments, precursors, and trade studies for Mars robotic missions
Exploration Flight Test Objective Logic Flow

**EM-1**
- Ground Launch Support & Infrastructure [N/A]
- Core Stage & Booster Ascent [8]
- Vehicle Operations Execution & Planning [1]
- Capsule Recovery and Return Operations [1]
- Cis-lunar Transport & Return Vehicle [6]
- Extended duration vehicle function (>21 days)

**EM-2**
- Crewed Capsule Recovery [1]
- Crewed Operations Integration
- Crewed Flight Systems [2]
- Exploration Upper Stage Performance
- Co-Manifested payload Integration & Deployment [NEW]
- Potential RPOD Secondary Objectives [NEW]

**EM-3 Goals**
- Core Launch and Flight Capability
- 4 Crew 21 day Cis-lunar Capability
- Payload Element Capability
- Rendezvous, Prox Ops, and Docking

[x] = Qty associated ESD FTOs
* Pending update against HEOMD strategy & objectives

Leveling of mission objectives reduces risk and enables measurable progress against long-term agency strategy*
EM-1 Mission Profile

Total Mission Duration: 25-26 days

- Return (DRI to EI): 5-13 days
- Outbound (TLI to DRI): 6-14 days

EM-1 Mission Profile Considerations

- Demonstrates initial SLS vehicle performance
- Provides for challenging, extended (3 week) test of uncrewed Orion systems in the deep space environment
- Demonstrates ability to enter, operate in, and exit DRO
- DRO remains an option for ARCM and Mars transit vehicle aggregation in the Proving Ground
Systems demonstrated ahead of crewed EM-2 flight:

- Orion (LAS staging, power and thermal systems, navigation and control, communications with DSN, thermal protection system, re-entry and recovery)
- SLS (core stage and booster performance, stack controllability, staging, disposal)
- EGS (integration, secondary payload processing, tanking, launch commit criteria, recovery)
EM-2 Mission Profile Considerations:

- 2-orbit detailed test objective permits checkout of crewed systems in highly elliptical orbit around the Earth before committing to Orion TLI

- Free return provides return capability within suit consumable limits (144 hours); mission extension options post-TLI burn if all systems nominal

- EUS TLI disposal burn post-Orion separation maximizes co-manifested payload capability
EM-2 Mission Objectives

12 of 28 Exploration Objectives Complete or In Work Following Success of EM-2

Accommodations for up to 6+ metric tons (growing to 10mT by EM-4) and 286m³ of co-manifested payload
**Baseline Exploration Systems Capability**

*NOTE: NASA’s schedule agency baseline commitments for launch readiness are November 2018 for SLS and EGS, and August 2023 for Orion (first crewed flight). However, NASA is working toward the crewed EM-2 flight in 2021.*

<table>
<thead>
<tr>
<th></th>
<th>EM-1</th>
<th>EM-2</th>
<th>EM-3</th>
<th>EM-4</th>
<th>EM-5</th>
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<th>EM-8</th>
<th>EM-9</th>
<th>EM-10</th>
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<tbody>
<tr>
<td><strong>Launch Planning Date</strong></td>
<td>NLT Nov 2018*</td>
<td>Aug 2021*</td>
<td>2023</td>
<td>2024</td>
<td>2025</td>
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<td>2027</td>
<td>2028</td>
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<td><strong>SLS Block Configuration</strong></td>
<td>Block 1</td>
<td>Block 1B</td>
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<td>6-10 mT</td>
<td>6-10 mT</td>
<td>6-10 mT</td>
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<td>10+ mT</td>
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<td>TBD cubesat slots</td>
<td>TBD cubesat slots</td>
<td>TBD cubesat slots</td>
<td>TBD cubesat slots</td>
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<td><strong>Orion Crew</strong></td>
<td>Uncrewed</td>
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<td><strong>Orion Mission Type</strong></td>
<td>Lunar Orbit</td>
<td>Proving Ground</td>
<td>Proving Ground</td>
<td>Proving Ground</td>
<td>Proving Ground</td>
<td>ARCM</td>
<td>Proving Ground</td>
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<td>Proving Ground</td>
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<td><strong>Service Module (SM) Provider</strong></td>
<td>ESA</td>
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<td>ESA*</td>
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<tr>
<td><strong>Mission Duration Capability</strong></td>
<td>26 days</td>
<td>21 days</td>
<td>21 days</td>
<td>21 days</td>
<td>25-28 days</td>
<td>30+ days</td>
<td>30+ days</td>
<td>30+ days</td>
<td>30+ days</td>
<td>30+ days</td>
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</table>

* Pending formal Agreement

** Notional

For Planning Purposes Only
Summary

• HEO has a solid approach for advancing human presence into deep space
  – Approach is consistent with strategic guidance
  – Open to changes in policy, guidance and funding

• Hardware development for all HEO systems (crew, cargo, habitation, SLS-Orion) is progressing well with challenges as expected

• HEO is decomposing requirements into test objectives for near term missions and defining mission capabilities within the constraints of safety, risk tolerance and hardware maturity

• ISS operations are doing well and proving the worth of real operations in LEO in order to develop systems (human and hardware) for deep space operations

• ISS role in enabling international cooperation for Orion service module is beneficial

• Exploration will involve international partners habitation work is being defined

• Next Step BAA is involving private in exploration

• Current International partnerships are strong for ISS and open to new participants

• Research on ISS is advancing state of the art, commercial interest is rising, and number of new investigations is increasing

• Solid plan for habitation improvements and health risks for deep space are being mitigated

• Communication and launch services meeting all users needs and building for the future
Final thoughts

• Human exploration provides many benefits to the nation and humanity
  – Inspiration
  – Hope for the future
  – Challenges that need the support from a diverse international community
  – International leadership in technology
  – Direct benefits to the terrestrial population

• NASA is well posed to assist the nation in achieving these benefits and more
Phase 0: Exploration Systems Testing on ISS and in LEO
Leverage the ISS as a test bed to demonstrate key exploration capabilities and operations, and foster an emerging commercial space industry in LEO.

Phase 1: Cislunar Demonstration of Exploration Systems
Demonstration of the integrated SLS and Orion; culminates in the Asteroid Redirect Crewed Mission (ARCM) in the mid-2020s.

Phase 2: Cislunar Validation of Exploration Systems
Validation of integrated SLS, Orion, habitation, crew, and in-space transportation systems in cislunar space; culminates in the capstone a one- to three- year crewed “shakedown cruise” of a Mars transit habitation capability in the 2030 timeframe.
### Phase 0 Objectives

<table>
<thead>
<tr>
<th>Objective Identifier</th>
<th>Objective</th>
<th>Objective Category</th>
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</thead>
<tbody>
<tr>
<td>P0-01</td>
<td>Acquire routine round-trip U.S. crew transportation to LEO</td>
<td>Transportation</td>
</tr>
<tr>
<td>P0-02</td>
<td>Acquire routine U.S. cargo transportation to LEO</td>
<td>Transportation</td>
</tr>
<tr>
<td>P0-03</td>
<td>Evaluate communications with increased delay</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-04</td>
<td>Demonstrate in-space exploration class extra-vehicular activity (EVA) technologies</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-05</td>
<td>Demonstrate exploration environmental control and life support system (ECLSS) and environmental monitoring technologies and validate real-time on-orbit environmental monitoring</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-06</td>
<td>Validate in-space fire detection, suppression, and cleanup technologies suitable for exploration missions</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-07</td>
<td>Demonstrate radiation monitoring technologies in LEO and evaluate radiation mitigation capabilities</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-08</td>
<td>Demonstrate autonomous operations in LEO</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-09</td>
<td>Demonstrate human and robotic mission operations</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-10</td>
<td>Evaluate technologies that may enable operations with reduced logistics capabilities</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-11</td>
<td>Demonstrate docking and close-proximity technologies and operations</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-12</td>
<td>Enable science community objectives in low earth orbit</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P0-13</td>
<td>Demonstrate crew acclimatization to/from zero-g</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P0-14</td>
<td>Demonstrate medical diagnosis capability and treatment protocols for exploration missions</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P0-15</td>
<td>Demonstrate protocols to understand crew task performance and operations planning for human space missions</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P0-16</td>
<td>Demonstrate countermeasures to mitigate the hazards of long duration spaceflight</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P0-17</td>
<td>Demonstrate long duration viability &amp; stability of food and pharmaceuticals</td>
<td>Staying Healthy</td>
</tr>
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</table>
# Phase 1 Objectives

<table>
<thead>
<tr>
<th>Objective Identifier</th>
<th>Objective</th>
<th>Objective Category</th>
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</thead>
<tbody>
<tr>
<td>P1-01</td>
<td>Demonstrate SLS Block 1 elements in flight and integrated performance with Orion</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-02</td>
<td>Demonstrate Block 1B trans-lunar injection (TLI) performance</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-03</td>
<td>Demonstrate SLS Block 1B co-manifested capability</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-04</td>
<td>Demonstrate Orion's ability to support crew in deep space</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-05</td>
<td>Demonstrate Orion's ability in conjunction with additional habitation element(s) to support missions with at least 4-Crew for a minimum of 30 days</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-06</td>
<td>Demonstrate operation of long-duration high power solar arrays and solar electric propulsion (SEP) transportation of in-space propulsion elements</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-07</td>
<td>Demonstrate ability to stage habitation and other capabilities in deep space for later utilization</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-08</td>
<td>Demonstrate ability for crewed rendezvous and operation with a previously staged element(s)</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-09</td>
<td>Demonstrate autonomous rendezvous, proximity operations, and docking in deep space</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-10</td>
<td>Demonstrate ability to dispose of assets from deep space</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-11</td>
<td>Demonstrate automatic deep space trajectory design, planning, and navigation</td>
<td>Transportation</td>
</tr>
<tr>
<td>P1-12</td>
<td>Demonstrate deep space crewed operations up to Mars communications latency</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-13</td>
<td>Validate ability to conduct EVA in deep space</td>
<td>Working in Space</td>
</tr>
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</table>
### Phase 1 Objectives

**Continued**

<table>
<thead>
<tr>
<th>P1-14</th>
<th>Validate integrated radiation risk mitigation ability to provide As Low As Reasonably Acceptable (ALARA) exposure, including monitoring, mitigation, and operational strategies</th>
<th>Working in Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1-15</td>
<td>Demonstrate transition between crewed and uncrewed operations</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-16</td>
<td>Demonstrate human/robotic interactions in deep space</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-17</td>
<td>Demonstrate stowage strategies within available volume for deep space missions</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-18</td>
<td>Demonstrate the collection and return of geologic, biological and/or scientific samples including planetary protection protocols.</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-19</td>
<td>Evaluate the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-20</td>
<td>Demonstrate crew operations with a natural space object in a low gravity environment</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-21</td>
<td>Enable science community objectives in deep space</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-22</td>
<td>Enable commercial and international partnership objectives in deep space</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-23</td>
<td>Demonstrate ability to use an uncrewed capability to enable science, technology, and exploration</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P1-24</td>
<td>Demonstrate/evaluate exploration medical capabilities</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P1-25</td>
<td>Demonstrate/evaluate human flight operations crew physiological well-being in deep space</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P1-26</td>
<td>Demonstrate/evaluate human flight operations crew psychological well-being in deep space</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P1-27</td>
<td>Demonstrate/evaluate human health countermeasures</td>
<td>Staying Healthy</td>
</tr>
<tr>
<td>P1-28</td>
<td>Evaluate the effects of deep space on complex organisms, plants, food, pharmaceuticals, and animal models</td>
<td>Staying Healthy</td>
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### Phase 2 Objectives

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<thead>
<tr>
<th>Objective Identifier</th>
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<tr>
<td>P2-01</td>
<td>Demonstrate SLS Block 2 trans-lunar injection (TLI) performance</td>
<td>Transportation</td>
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<tr>
<td>P2-02</td>
<td>Demonstrate SLS Block 2 co-manifested capability and cargo only capability</td>
<td>Transportation</td>
</tr>
<tr>
<td>P2-03</td>
<td>Validate long-duration, long-distance in-space propulsion capabilities, including refueling and long-term fuel storage</td>
<td>Transportation</td>
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<tr>
<td>P2-04</td>
<td>Validate high bandwidth and high data rate deep space communication capabilities to support real-time high resolution video</td>
<td>Working in Space</td>
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<tr>
<td>P2-05</td>
<td>Validate capability and reliability of ECLSS to support a Mars class mission including dormancy periods</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P2-06</td>
<td>Validate Mars class habitation system transition between crewed and uncrewed operations</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P2-07</td>
<td>Demonstrate use of the habitat capability to conduct remote robotic operation of systems</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P2-08</td>
<td>Validate Mars habitat integrated system performance and reliability in deep space</td>
<td>Working in Space</td>
</tr>
<tr>
<td>P2-09</td>
<td>Demonstrate the ability to conduct extended missions in deep space leading to a Mars class transit duration</td>
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<tr>
<td>P2-10</td>
<td>Validate maintenance and repair capabilities in deep space with limited or no resupply</td>
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<tr>
<td>P2-11</td>
<td>Evaluate capabilities to produce and store resources in-situ for ascent propellant and life support consumables in deep space</td>
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<tr>
<td>P2-12</td>
<td>Enable science community objectives in deep space</td>
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<tr>
<td>P2-13</td>
<td>Enable commercial and international partnership objectives in deep space</td>
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<tr>
<td>P2-14</td>
<td>Validate exploration medical capabilities in deep space</td>
<td>Staying Healthy</td>
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<td>-------</td>
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<tr>
<td>P2-15</td>
<td>Validate human flight operations crew physiological well-being on Mars class missions</td>
<td>Staying Healthy</td>
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<tr>
<td>P2-16</td>
<td>Validate human flight operations crew psychological well-being on Mars class missions</td>
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<tr>
<td>P2-17</td>
<td>Demonstrate Mars flight mass and form factor exercise system capability and reliability</td>
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<tr>
<td>P2-18</td>
<td>Validate human health countermeasures</td>
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# Exploration Objectives by Mission

**NOTE:** Draft assessment; alignment of Exploration Objectives to mission objectives is forward work

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<thead>
<tr>
<th>Exploration Objectives</th>
<th>EM-1</th>
<th>EM-2</th>
<th>EM-3</th>
<th>EM-4</th>
<th>EM-5</th>
<th>EM-6</th>
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<td>P1-01 Demonstrate SLS Block 1 elements in flight and integrated performance with Orion</td>
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<tr>
<td>P1-02 Demonstrate Block 1B trans-lunar injection (TLI) performance</td>
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<td>P1-03 Demonstrate SLS Block 1B co-manifested capability</td>
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<td>P1-04 Demonstrate Orion’s ability to support crew in deep space</td>
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<td>P1-05 Demonstrate Orion’s ability in conjunction with additional habitation element(s) to support missions with at least 4-Crew for a minimum of 30 days</td>
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<td>P1-06 Demonstrate operation of long-duration high power solar arrays and solar electric propulsion (SEP) transportation of in-space propulsion elements</td>
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<td>P1-07 Demonstrate ability to stage habitation and other capabilities in deep space for later utilization</td>
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<td>P1-08 Demonstrate ability for crewed rendezvous and operation with a previously staged element(s)</td>
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<td>P1-09 Demonstrate autonomous rendezvous, proximity operations, and docking in deep space</td>
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<td>P1-10 Demonstrate ability to dispose of assets from deep space</td>
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<td>P1-11 Demonstrate autonomous deep space trajectory design, planning, and navigation</td>
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<td>P1-12 Demonstrate deep space crewed operations up to Mars communications latency</td>
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<td>P1-13 Validate ability to conduct EVA in deep space</td>
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<td>P1-14 Validate integrated radiation risk mitigation ability to provide As Low As Reasonably Acceptable (ALARA) exposure, including monitoring, mitigation, and operational strategies</td>
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<td>P1-15 Demonstrate transition between crewed and uncrewed operations</td>
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<td>P1-16 Demonstrate human/robotic interactions in deep space</td>
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<td>P1-17 Demonstrate stowage strategies within available volume for deep space missions</td>
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<td>P1-18 Demonstrate the collection and return of geologic, biological and/or scientific samples including planetary protection protocols.</td>
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<td>P1-19 Evaluate the nature and distribution of volatiles and extraction techniques and decide on their potential use in human exploration architecture</td>
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<td>P1-20 Demonstrate crew operations with a natural space object in a low gravity environment</td>
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<td>P1-21 Enable science community objectives in deep space</td>
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<td>P1-22 Enable commercial and international partnership objectives in deep space</td>
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<td>P1-23 Demonstrate ability to use an uncrewed capability to enable science, technology, and exploration</td>
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<td>P1-24 Demonstrate/evaluate exploration medical capabilities</td>
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<td>P1-25 Demonstrate/evaluate human flight operations crew physiological well-being in deep space</td>
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<td>P1-26 Demonstrate/evaluate human flight operations crew psychological well-being in deep space</td>
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<td>P1-27 Demonstrate/evaluate human health countermeasures</td>
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<td>P1-28 Evaluate the effects of deep space on complex organisms, plants, food, pharmaceuticals, and animal models</td>
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We are well on the way to EM-1
EM-1 Secondary Payloads

- **Cubesat to Study Solar Particles (CuSP)**
  - Payload Developer: Southwest Research Institute (SwRI)
  - Objective: Observations of Interplanetary Space environment to gain insight into space weather
  - Destination: Heliocentric Trajectory
- **LUNAr polar Hydrogen Mapper (LunaH-Map)**
  - Payload Developer: Arizona State University (ASU)
  - Objective: Perform neutron spectroscopy of lunar surface to determine H abundance
  - Mission Destination: Lunar Orbit
- **Lunar Flashlight**
  - Payload Developer: Jet Propulsion Laboratory
  - Objective: Search for lunar surface ice deposits using near-IR band lasers
  - Mission Destination: Lunar Orbit
- **Near Earth Asteroid Scout (NEA Scout)**
  - Payload Developer: Marshall Space Flight Center
  - Objective: Perform target detection, reconnaissance and close proximity imaging of a NEA
  - Mission Destination: a Near Earth Asteroid (within ~1.0 AU distance from Earth)
- **BioSentinel**
  - Payload Developer: Ames Research Center
  - Objective: Quantify DNA damage from space radiation environment
  - Destination: Heliocentric Trajectory
- **Lunar IceCube**
  - Payload Developer: Moorehead State University
  - Objective: Prospect for water (ice, liquid & vapor) & other lunar volatiles using IR spectrometer
  - Mission Destination: Lunar Orbit
- **SkyFire**
  - Payload Developer: Lockheed Martin Space Systems
  - Objective: Collect IR imaging of Lunar Surface
  - Mission Destination: Heliocentric via Lunar Flyby
- **ArgoMoon**
  - Payload Developer: ASI
  - Objective: Provide photography of EM-1 Mission, detailed imagery of ICPS as well as demonstrate image system operability
  - Mission Destination: Elliptical Earth Orbit (ICPS proximity)
- **Outstanding Moon exploration TEnchnologies demonstrated by NAno Semi-Hard Impactor (OMOTENASHI)**
  - Payload Developer: JAXA
  - Objective: Develop worlds smallest lunar lander and observe lunar radiation environment
  - Mission Destination: Lunar Surface
- **EQUULEUS**
  - Payload Developer: JAXA
  - Objective: Characterize radiation environment in geospace by imaging the Earth’s plasmasphere
  - Mission Destination: Earth-Moon L2
EM-1 Secondary Payload Candidates

- The three final secondary payloads will be selected via the STMD Centennial Challenges
  - Final selection from the 6 candidates below will be made Feb 2017

- **MIT KitCube**
  - Payload Developer: Massachusetts Institute of Technology
  - Objective: Compete in **Lunar Derby** for the Achieve Lunar Orbit, Best Burst Data Rate, Largest aggregate Data Volume Sustained over time and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

- **Team Miles**
  - Payload Developer: Fluid & Reason, LLC
  - Objective: Compete in the **Deep Space Derby** for Furthest Communication Distance from Earth prize
  - Mission Destination: Deep Space

- **Cislunar Explorers**
  - Payload Developer: Cornell University
  - Objective: Compete in the **Lunar Derby** for Achieving Lunar Orbit and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

- **Heimdallr**
  - Payload Developer: Ragnarok Industries
  - Objective: Compete in the **Lunar Derby** for the Achieve Lunar Orbit, Best Burst Data Rate, Largest aggregate Data Volume Sustained over time and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit

- **CU-E3**
  - Payload Developer: University of Colorado
  - Objective: Compete in the **Deep Space Derby** for Best Burst Data Rate, Largest Aggregate Data Volume Sustained over time, Spacecraft Longevity and Furthest Communication Distance from Earth prizes
  - Mission Destination: Deep Space

- **SEDS Triteria**
  - Payload Developer: University of California San Diego
  - Objective: Compete in the **Lunar Derby** for the Achieve Lunar Orbit and Spacecraft Longevity prizes
  - Mission Destination: Lunar Orbit
EM-2 Co-manifested Payload RFI

- 10/5 ESD released an RFI to assess the available range of Co-manifested Payloads and interest of candidate CPL providers for EM-2
- Information requested for 2 Co-manifested Payload Sizes: large co-manifested payloads up to 6,000 kg and smaller, stackable (ESPA-class) co-manifested payloads approximately up to 300 kg
- RFI closed 11/7, responses are in review
The Habitation Development Challenge

800-1,100 DAYS
Total crew time away from Earth:
• Microgravity
• Radiation
• Autonomy
• Human-Robotic Ops

HABITATION CAPABILITY

Habitation Systems Technologies
• Environmental Control & Life Support
• Autonomous Systems
• EVA
• Fire Safety
• Radiation Protection

Habitation Systems Crew Health
• Human Research
• Human Performance
• Exercise
• Nutrition

Integrated Habitats
• Studies and ground prototypes of pressurized volumes
Specific Habitation Systems Objectives

Habitation Systems Elements

1. LIFE SUPPORT
   - Atmosphere Management
   - Waste Management

2. ENVIRONMENTAL MONITORING
   - Pressure O₂ & N₂
   - Moisture
   - Particles
   - Microbes
   - Chemicals
   - Sound

3. CREW HEALTH
   - Monitoring
   - Exercise
   - Diagnostics
   - Treatment
   - Food Storage & Management

4. EVA: EXTRA-VEHICULAR ACTIVITY
   - Mobility
   - Life Support
   - Science and Exploration

TODAY
- ISS
- 42% O₂ Recovery from CO₂
- 90% H₂O Recovery
- < 6 mo mean time before failure (for some components)

FUTURE
- Deep Space
- 75%+ O₂ Recovery from CO₂
- 98%+ H₂O Recovery
- >30 mo mean time before failure

LIFE SUPPORT
- 75%+ O₂ Recovery from CO₂
- 98%+ H₂O Recovery
- >30 mo mean time before failure

ENVIRONMENTAL MONITORING
- Limited, crew-intensive on-board capability
- Reliance on sample return to Earth for analysis

CREW HEALTH
- Bulky fitness equipment
- Limited medical capability
- Frequent food system resupply

EVA: EXTRA-VEHICULAR ACTIVITY
- High upper body mobility for limited sizing range
- Low interval between maintenance, contamination sensitive, and consumables limit EVA time
- Construction and repair focused tools; excessive inventory of unique tools

Full body mobility for expanded sizing range
- Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time
- Geological sampling and surveying equipment; common generic tool kit

Smaller, efficient equipment
- Onboard medical capability
- Long-duration food system

Smaller, efficient equipment
- Onboard medical capability
- Long-duration food system
Specific Habitation Systems Objectives

Habitation Systems Elements

5. **RADIATION PROTECTION**
   - Monitoring
   - Tracking
   - Modeling
   - Mitigation

   - Node 2 crew quarters (CQ) w/ polyethylene reduce impacts of proton irradiation.
   - RAD, REM – real-time dosimetry, monitoring, tracking, model validation & verification
   - TEPC, IVTEPC – real-time dosimetry
   - CPD, RAM – passive dosimeters

6. **FIRE SAFETY**
   - Detection
   - Suppression
   - Cleanup

   - Large CO₂ Suppressant Tanks
   - 2-cartridge mask
   - Obsolete combustion prod. sensor
   - Only depress/repress clean-up

7. **LOGISTICS**
   - Tracking
   - Clothing
   - Packaging
   - Trash

   - Manual scans, displaced items
   - Disposable cotton clothing
   - Packaging disposed
   - Bag and discard

   - Automatic, autonomous RFID
   - Long-wear clothing & laundry
   - Bags/foam repurposed w/3D printer
   - Resource recovery, then disposal

8. **CROSS-CUTTING**
   - Robotics
   - Communication
   - Docking
   - Autonomy & Software
   - Thermal
   - Materials

   - Minimal on-board autonomy
   - Near-continuous ground-crew comm
   - Some common interfaces, modules controlled separately
   - Ops independent of Earth & crew
   - Up to 40-minute comm delay
   - Widespread common interfaces, modules/systems integrated
   - Manufacture replacement parts in space
Deep-Space Habitation Development Strategy

Proving Ground Phase 0:
SYSTEMS DEVELOPMENT AND TESTING ON ISS / LEO

- Bigelow Expandable Activity Module
- Spacecraft Fire Safety
- Logistics Management

Habitation Systems Development
Advanced Exploration Systems & Human Research Program

- Life Support Systems
- Docking Hatch
- Advanced Avionics
- EVA
- Radiation Detection

Proving Ground Phase 1:
DEEP SPACE TESTING
- Initial Cislunar Habitation

Proving Ground Phase 2:
DEEP SPACE VALIDATION
- Long Duration Habitation
- Validation Cruise