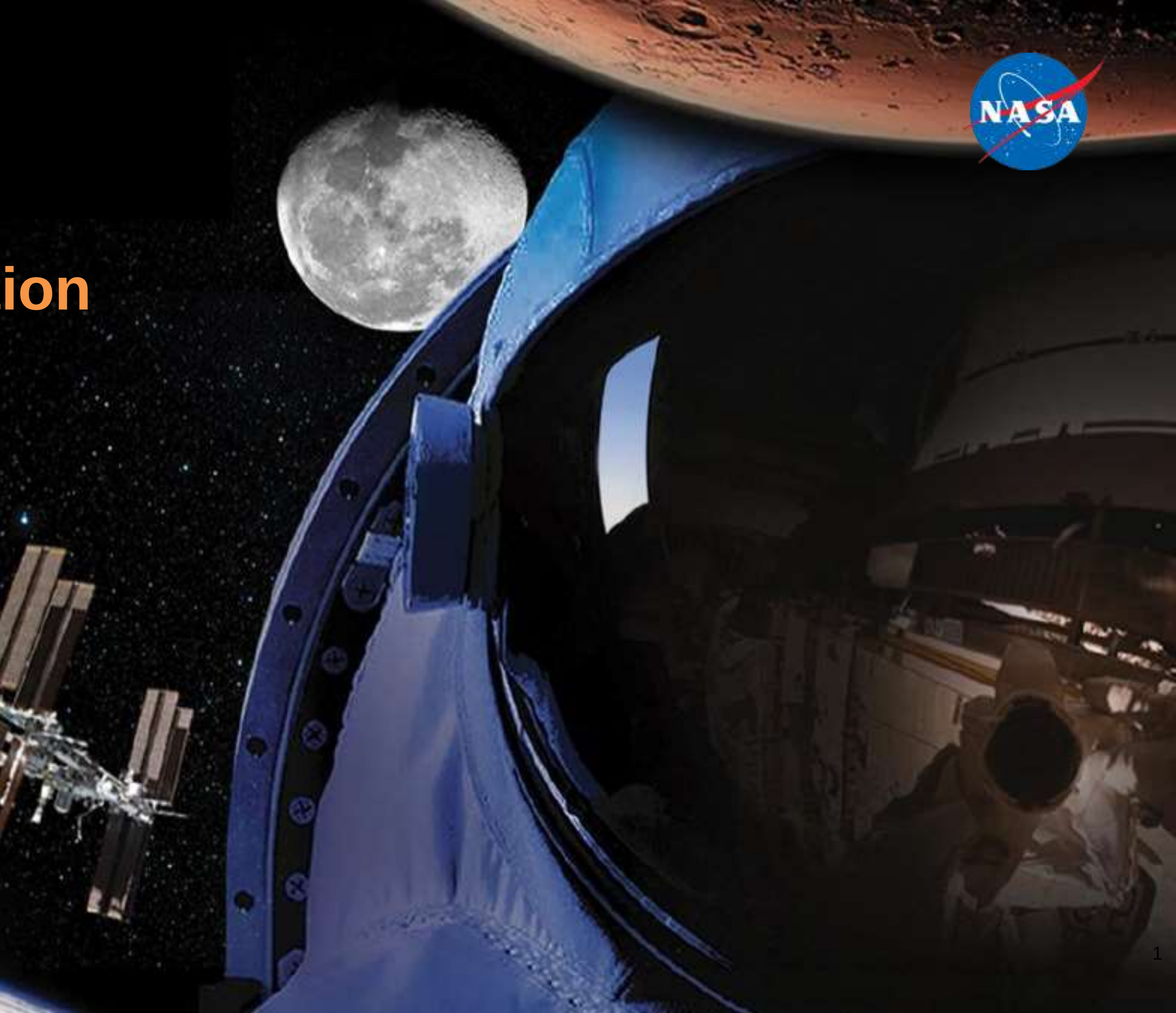
National Aeronautics and Space Administration

# Advanced Exploration Systems




10 October 2017

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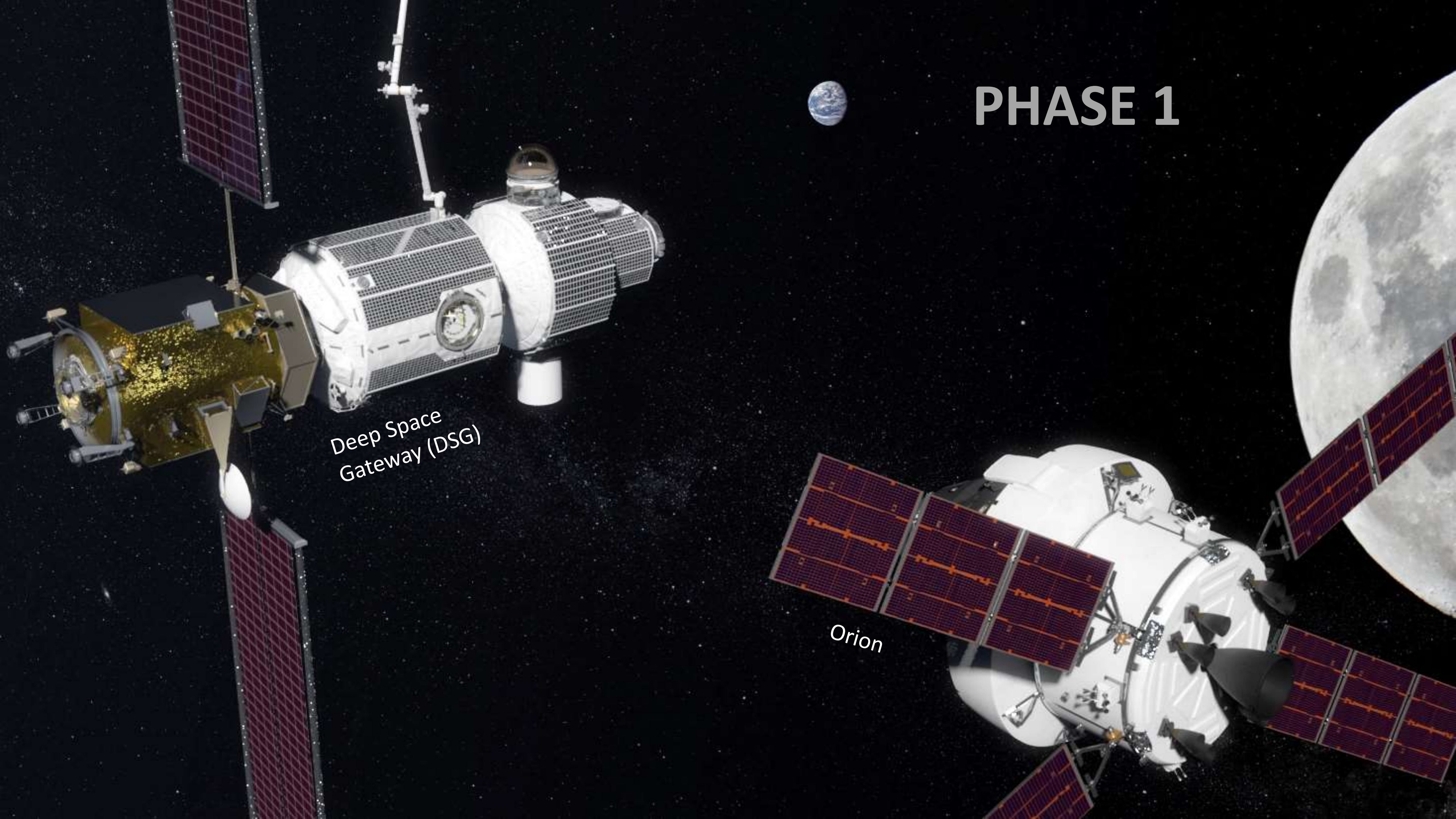
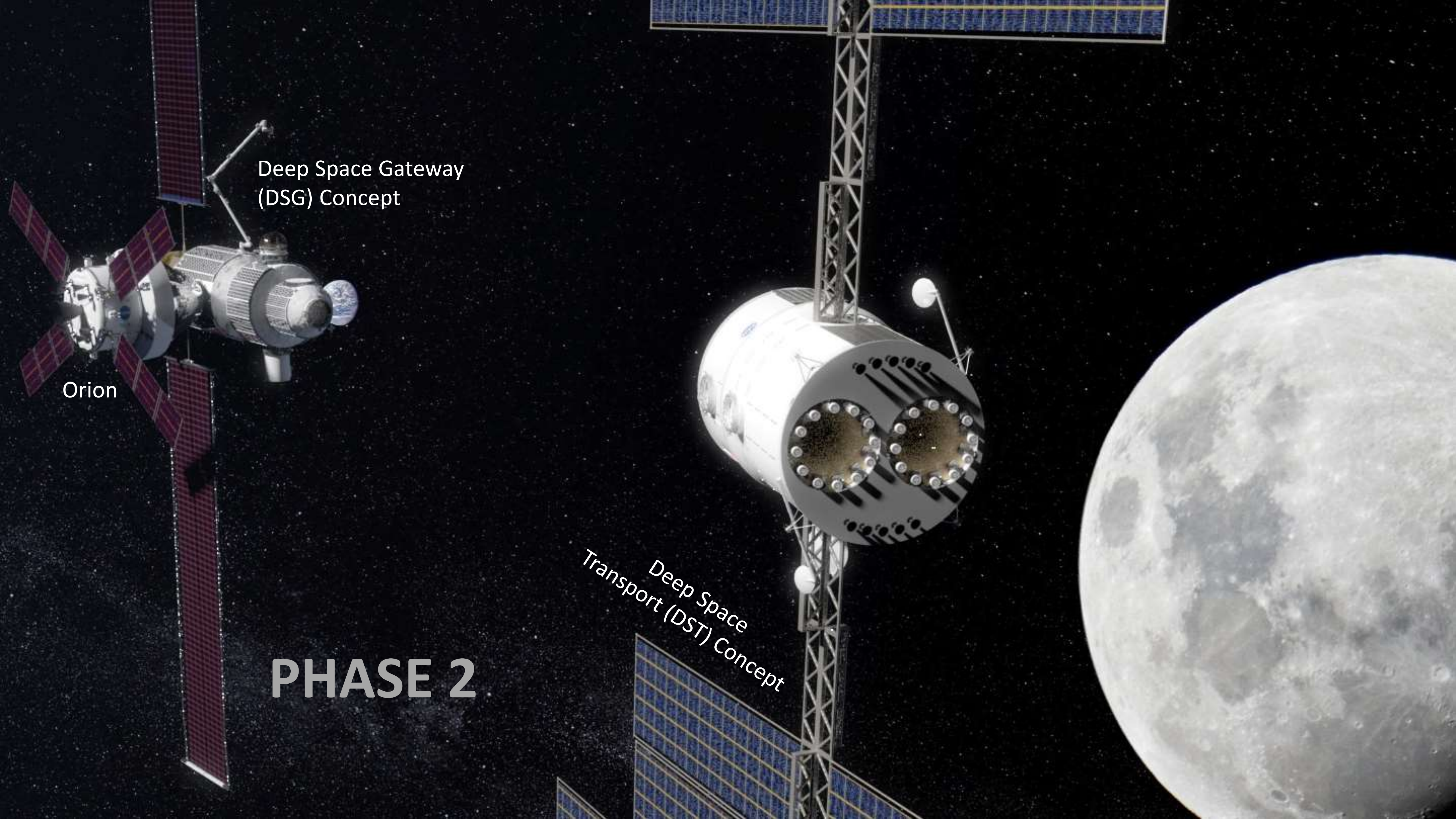
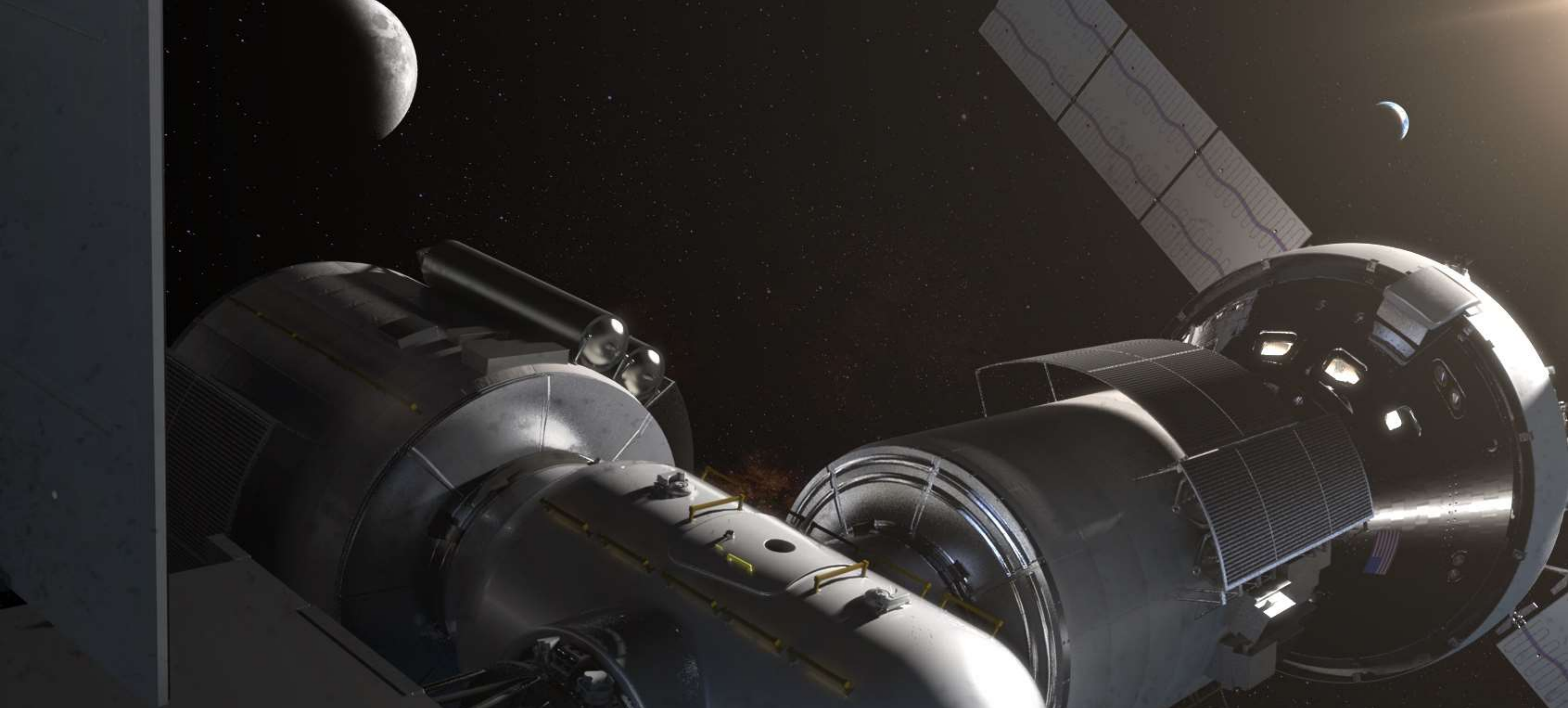
NASA Headquarters

National Aeronautics and
Space Administration


# ADVANCED EXPLORATION SYSTEMS


PHASE 1
Deep Space Gateway (DSG)
Orion


Deep Space Gateway
(DSG) Concept
Orion
Deep Space
Transport (DST) Concept
PHASE 2



# HABITATION CAPABILITY

Systems to enable crews to live and work safely in deep space. Capabilities and systems will be used in conjunction with Orion and SLS on exploration missions in cislunar space and beyond.

# DEEP SPACE HABITATION SYSTEMS

## Habitation Systems Elements

| | TODAY Space Station | FUTURE Deep Space |
|---|---|---|
| **LIFE SUPPORT**<br>Excursions from Earth are possible with artificially produced breathing air, drinking water and other conditions for survival.<br>Atmosphere Management; Water Management; Waste Management | 42% $O_2$ Recovery from $CO_2$<br>90% $H_2O$ Recovery<br>< 6 mo mean time before failure (for some components) | 75%+ $O_2$ Recovery from $CO_2$<br>98%+ $H_2O$ Recovery<br>>30 mo mean time before failure |
| **ENVIRONMENTAL MONITORING**<br>NASA living spaces are designed with controls and integrity that ensure the comfort and safety of inhabitants.<br>Pressure $O_2$ & $N_2$; Moisture; Particles; Microbes; Chemicals; Sound | Limited, crew-intensive on-board capability<br>Reliance on sample return to Earth for analysis | On-board analysis capability with no sample return<br>Identify and quantify species and organisms in air & water |
| **CREW HEALTH**<br>Astronauts are provided tools to perform successfully while preserving their well-being and long-term health.<br>Monitoring; Exercise; Diagnostics; Treatment; Food Storage & Management | Bulky fitness equipment<br>Limited medical capability<br>Frequent food system resupply | Smaller, efficient equipment<br>Onboard medical capability<br>Long-duration food system |
| **EVA: EXTRA-VEHICULAR ACTIVITY**<br>Long-term exploration depends on the ability to physically investigate the unknown for resources and knowledge.<br>Mobility; Life Support; Science and Exploration | High upper body mobility for limited sizing range<br>Low interval between maintenance, contamination sensitive, and consumables limit EVA time<br>Construction and repair focused tools; excessive inventory of unique tools | Full body mobility for expanded sizing range<br>Increased time between maintenance cycles, contamination resistant system, 25% increase in EVA time<br>Geological sampling and surveying equipment; common generic tool kit |

# DEEP SPACE HABITATION SYSTEMS

## Habitation Systems Elements

| | Habitation Systems Elements | TODAY Space Station | FUTURE Deep Space |
|---|---|---|---|
| **RADIATION PROTECTION** | During each journey, radiation from the sun and other sources poses a significant threat to humans and spacecraft.<br>Monitoring, Tracking, Modeling, Mitigation | Node 2 crew quarters (CQ) with polyethylene reduce impacts of proton irradiation.<br>Large multi-layer detectors & small pixel detectors – real-time dosimetry, environment monitoring, tracking, model validation & verification<br>Bulky gas-based detectors – real-time dosimetry<br>Small solid-state crystal detectors – passive dosimetry (analyzed post-mission) | Solar particle event storm shelter, optimized position of on-board materials and CQ<br>Small distributed pixel detector systems – real-time dosimetry, environment monitoring, and tracking<br>Small actively read-out detectors for crew – real-time dosimetry |
| **FIRE SAFETY** | Throughout every mission, NASA is committed to minimizing critical risks to human safety.<br>Detection, Protection, Suppression, Cleanup | Large $CO_2$ Suppressant Tanks<br>2-cartridge mask<br>Obsolete combustion prod. sensor<br>Only depress/repress clean-up | Water Mist portable fire extinguisher<br>Single Cartridge Mask<br>Exploration combustion product monitor<br>Smoke eater |
| **LOGISTICS** | Sustainable living outside of Earth requires explorers to reduce, recycle, reuse, and repurpose materials.<br>Tracking, Clothing, Packaging, Trash | Manual scans, displaced items<br>Disposable cotton clothing<br>Packaging disposed<br>Bag and discard | Automatic, autonomous RFID<br>Long-wear clothing/laundry<br>Bags/foam repurposed w/3D printer<br>Resource recovery, then disposal |
| **CROSS-CUTTING** | Powerful, efficient, and safe launch systems will protect and deliver crews and materials across new horizons.<br>Robotics, Power, Communication, Docking, Avionics, Autonomy & Software, Thermal, Materials | Minimal on-board autonomy<br>Near-continuous ground-crew communications<br>Some common interfaces, modules controlled separately | Ops independent of Earth & crew<br>Up to 40-minute comm delay<br>Widespread common interfaces, modules/systems integrated<br>Manufacture replacement parts in space |

# Industry Partnerships in Pursuit of NASA's Strategic Goals

- **NextSTEP solicits studies, concepts, and technologies to demonstrate key capabilities on the International Space Station and for future human missions in deep space. Focus areas include:**
  - life support systems, advanced electric propulsion systems, small satellites, commercial lunar landers, and in-situ resource utilization (ISRU) measurements and systems
- **Most NextSTEP efforts require some level of corporate cost-sharing.**
- **This cost-sharing model of public-private partnerships stimulates the economy and fosters a stronger industrial base and commercial space market.**

# NEXTSTEP HABITATION OVERVIEW

## NextSTEP Phase 1: 2015-2016

Cislunar habitation concepts that leverage commercialization plans for LEO

LOCKHEED MARTIN

BIGELOW AEROSPACE

ORBITAL ATK

BOEING

### FOUR SIGNIFICANTLY DIFFERENT CONCEPTS RECEIVED

Partners develop required deliverables, including concept descriptions with concept of operations, NextSTEP Phase 2 proposals, and statements of work.

## NextSTEP Phase 2: 2016-2018

- Partners refine concepts and develop ground prototypes.
- NASA leads standards and common interfaces development.

### FIVE GROUND PROTOTYPES BY 2018






### ONE CONCEPT STUDY

NANORACKS

Define reference habitat architecture in preparation for Phase 3.

Initial discussions with international partners

## Phase 3: 2018+

- Partnership and Acquisition approach, leveraging domestic and international capabilities
- Development of deep space habitation capabilities
- Deliverables: flight unit(s)

# FULL-SIZED GROUND PROTOTYPE DEVELOPMENT

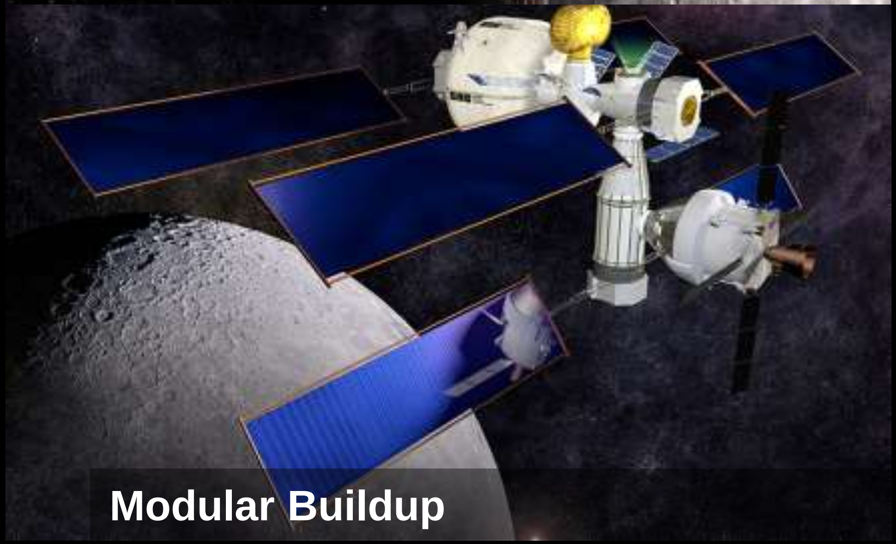
## DIFFERENT APPROACHES FOR BROAD TRADE SPACE OF OPTIONS


Expandable

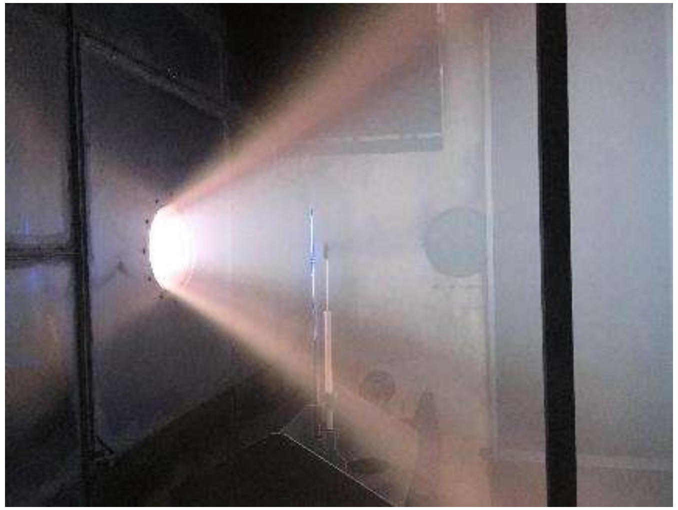

Leverages Existing Technologies


Builds on proven cargo spacecraft development

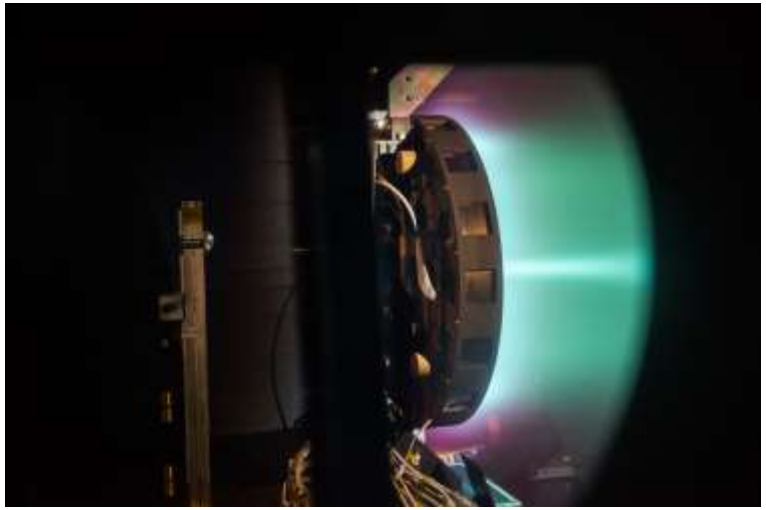

Refurbishes Heritage Hardware


Modular Buildup

# Developing propulsion technology systems in the 50- to 300-kW range to meet the needs of a variety of deep-space mission concepts



**Ad Astra Rocket Company:**
Variable Specific Impulse Magnetoplasma Rocket (VASIMR).

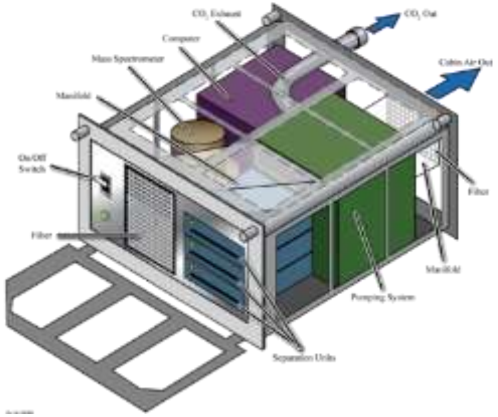


**Aerojet Rocketdyne:**
Nested Hall thruster

**MSNW**:
Electrodeless Lorentz Force plasma thruster.

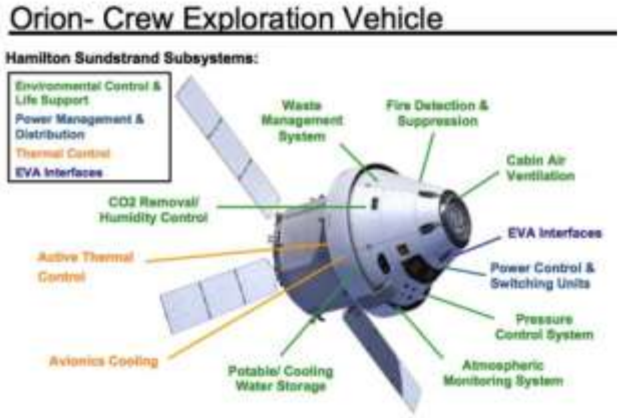
**NASA awarded seven habitation projects. Four will address habitat concept development, and three will address Environmental Control and Life Support Systems (ECLSS)**

**Dynetics, Inc**
Huntsville, AL



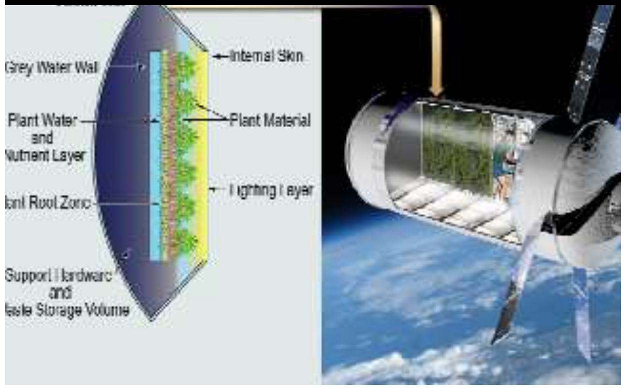
Miniature atmospheric scrubbing system for long-duration exploration and habitation applications. Separates CO2 and other undesirable gases from spacecraft cabin air

**Hamilton Sundstrand Space Systems International**
Windsor Locks, CT




Larger, more modular ECLSS subsystems, requiring less integration and maximize component commonality

**Sierra Nevada Corporation/Orbitec**
Madison, WI




Hybrid Life Support Systems integrating established Physical/Chemical life support with bioproduction systems

# IN-SPACE MANUFACTURING

## ON-DEMAND MANUFACTURING TECHNOLOGIES FOR DEEP SPACE MISSIONS

3-D printer installed on International Space Station in 2014. Crews aboard station have successfully used the printer to manufacture parts and tools on-demand.

Issued new appendix to NextSTEP Broad Agency Announcement soliciting proposals for development of first-generation, in-space, multi-material fabrication laboratory, or FabLab, for space missions.

First student-designed 3-D tool printed aboard station in 2016

In-Space Manufacturing logo created through Freelancer crowd-sourced challenge.

# BIGELOW EXPANDABLE ACTIVITY MODULE
# TWO-YEAR HABITAT DEMONSTRATION

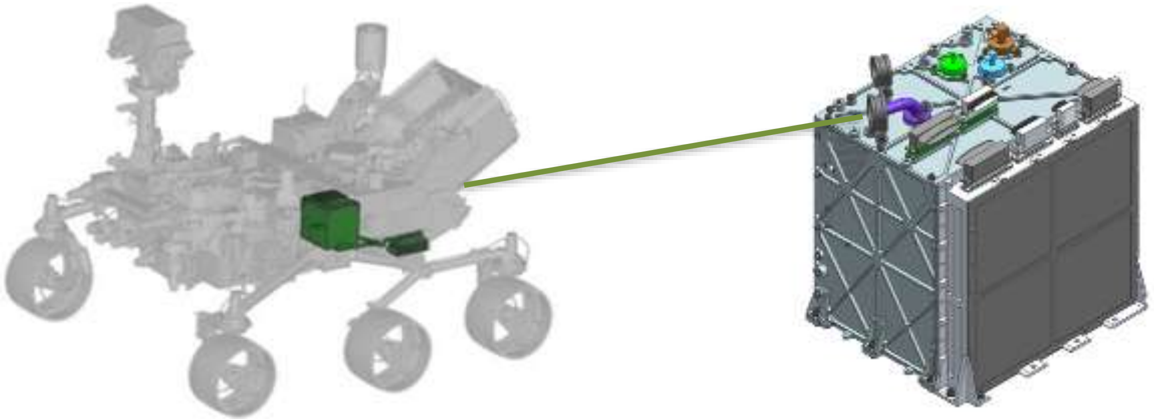
# SPACECRAFT FIRE SAFETY EXPERIMENTS (SAFFIRE)

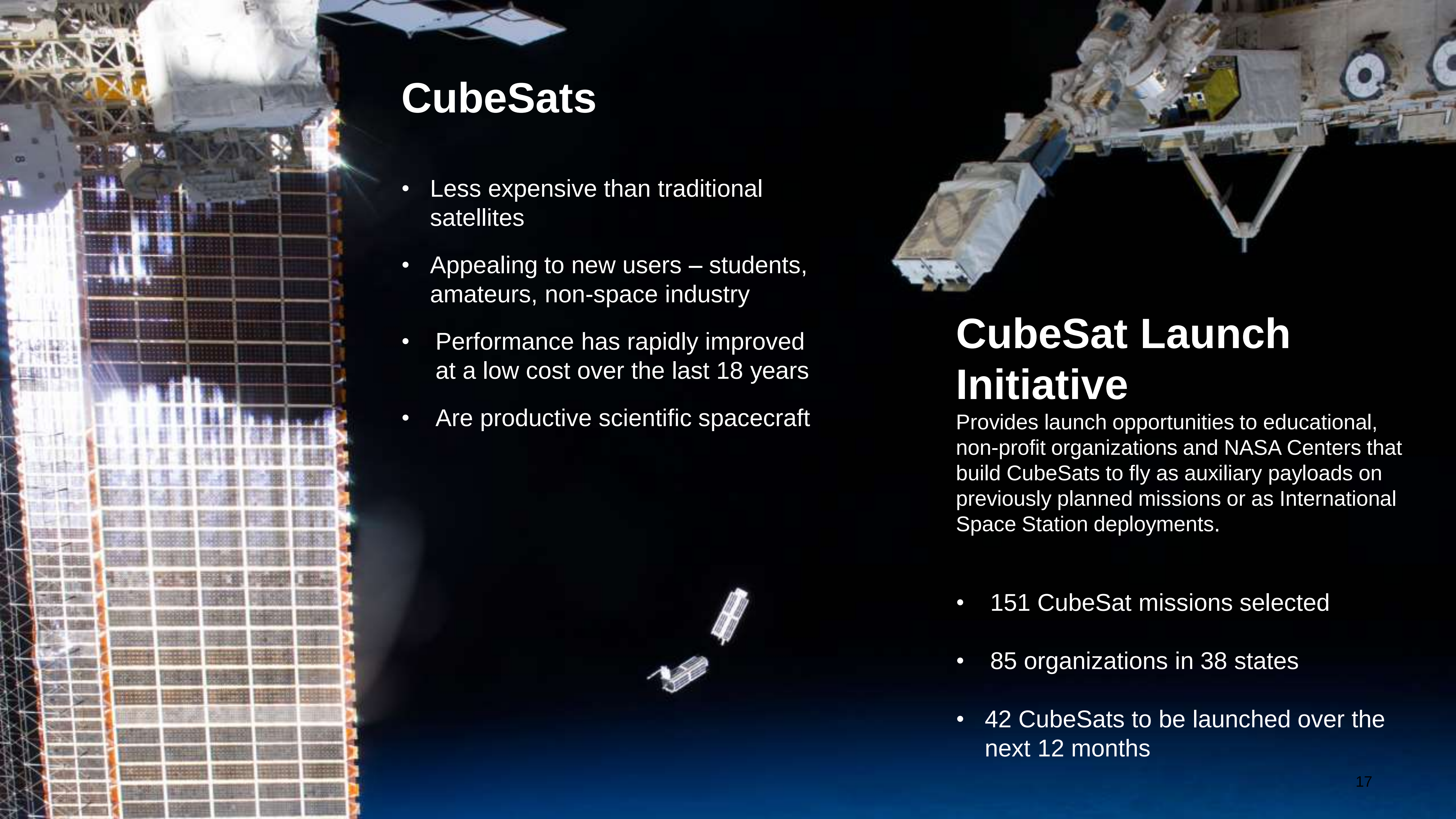
**Saffire-I&III:** cotton-fiberglass blend burn sample measured 0.4 m wide by 1 meter long

**Saffire-II:** nine samples in the experiment kit include a cotton-fiberglass blend, Nomex, and the same acrylic glass that is used for spacecraft windows

Extracting volatiles or building materials from extraterrestrial soils (regolith).

Extracting volatiles or consumables from extraterrestrial atmospheres.





# CubeSats

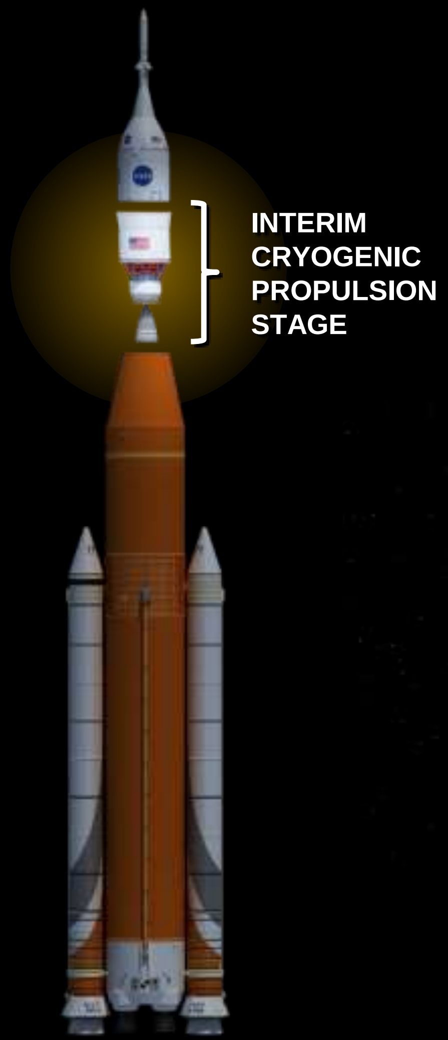
- Less expensive than traditional satellites
- Appealing to new users – students, amateurs, non-space industry
- Performance has rapidly improved at a low cost over the last 18 years
- Are productive scientific spacecraft

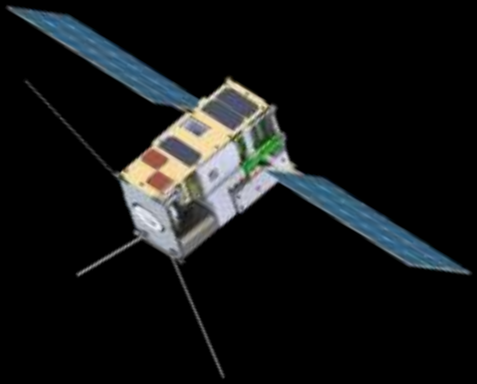
# CubeSat Launch Initiative

Provides launch opportunities to educational, non-profit organizations and NASA Centers that build CubeSats to fly as auxiliary payloads on previously planned missions or as International Space Station deployments.

- 151 CubeSat missions selected
- 85 organizations in 38 states
- 42 CubeSats to be launched over the next 12 months

# EM-1 Secondary Payloads



## 13 CUBESATS SELECTED TO FLY ON EM-1

- Lunar Flashlight
- Near Earth Asteroid Scout
- Bio Sentinel
- LunaH-MAP
- CuSPP
- Lunar IceCube
- LunIR
- EQUULEUS (JAXA)
- OMOTENASHI (JAXA)
- ArgoMoon (ESA)
- STMD Centennial Challenge Winners

# AES EM-1 Secondary Payloads: Strategic Knowledge Gaps and Key Technologies

| Payload | Technologies Advanced | Strategic Knowledge Gaps Addressed |
| --- | --- | --- |
| BioSentinel | • Deployable & Gimbaled Solar Arrays<br>• Attitude Determination Control System<br>• Integrated Microfluid Advancements<br>• Radiation Sensor Advancements | **Human health/performance in high-radiation space environments**<br>• Fundamental effects on biological systems of ionizing radiation in space environments |
| Lunar Flashlight | • Sphinx Flight Computer<br>• Iris (v2) transponder<br>• Green Propulsion<br>• Laser Sensors | **Lunar resource potential**<br>• Quantity and distribution of water and other volatiles in lunar cold traps |
| NEA Scout | • Cold Gas Propulsion<br>• Solar Sail technologies | **Human NEA mission target identification**<br>• NEA size, rotation state (rate/pole position)<br>**How to work on & interact with NEA surface**<br>• NEA surface mechanical properties |
| SkyFire | • Low SWAP<br>• High operating temperature MWIR sensor<br>• Infrared nBn Sensor | **Solar Illumination mapping and determination of Extent, magnitude, age of cold traps** |
| Lunar IceCube | • RF Ion Propulsion with Solid-state Iodine Propellant<br>• Low energy manifold trajectory<br>• Broadband (1 to 4 um) IR spectrometer | **Determination of: Temporal Variability and Movement Dynamics of Surface-Correlated OH and H2O deposits;** Composition, Form & Distribution of Polar Volatiles and quality/quantity/distribution/ form of H species, other volatiles in mare & highlands regolith. |

# Korea Pathfinder Lunar Orbiter (KPLO)

- NASA provides Deep Space Network, lunar navigation & trajectory assistance to the South Korean space agency (KARI) on their first lunar exploration mission *in return* for instrument space on the lunar orbiter:
  - 15kg, 15W payload allocation
  - Polar orbit, 100km altitude, 1 year mission
  - No exchange-of-funds agreement
- Select/develop/operate the NASA instrument
  - Joins 4 KARI-sponsored instruments + DTN
  - Deliver instrument to KARI September 2019
  - KPLO launches December 2020

**Lunar SKGs addressed:**

- Spatial and temporal distribution of volatiles
- Monitor movement of volatiles within PSRs
- Reveal the geomorphology, accessibility, and geotechnical characteristics of cold traps

# LunarCATALYST

Lunar CArgo Transportation And Landing bY Soft Touchdown

**In 2014, NASA competitively selected U.S. private-sector partners, based on likelihood of successfully fielding a commercially-viable lunar surface cargo transportation capability**

- Evaluation criteria included:
    - Technical approach and development schedules
    - Technical risks and mitigation plans
    - Business plans and market strategies
    - Equity and debt financing
    - Transportation service customer agreements

- **Lunar CATALYST Space Act Agreement (SAA) Partnerships**
  - Term: 3 years (2014-2017) with option to extend
  - No-funds-exchanged
  - Substantial in-kind contributions from NASA (~$10M/year)
    - Technical Expertise
    - Test Facilities
    - Equipment loans
    - Software
  - Technical and financial milestones
  - Partners:
    - Astrobotic Technology
    - Masten Space Systems
    - Moon Express

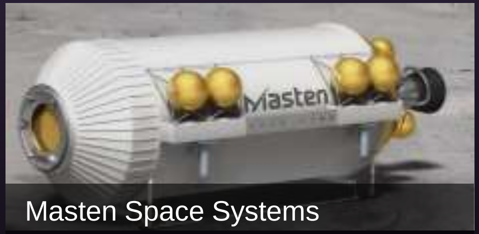
Helping our Industry partners to:

✓lower risks

✓conduct tests

✓accelerate vehicle development to launch

Moon Express




Masten Space Systems

Astrobotic Technologies

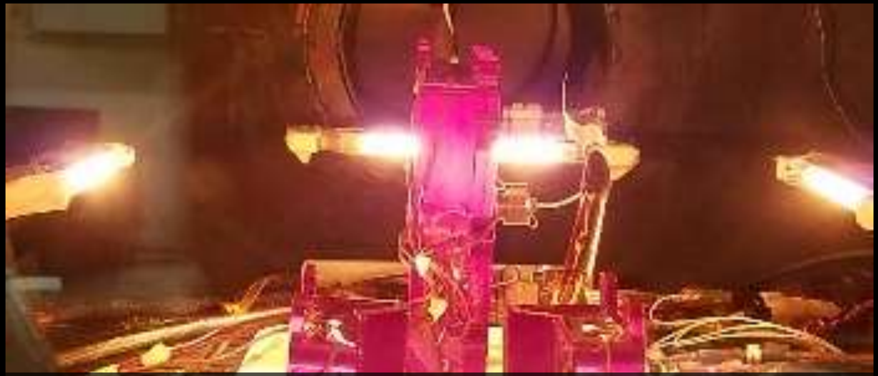
# RADIATION DETECTION & MITIGATION

5 Radiation Environment Monitors (REM) aboard ISS, 2 inside BEAM (pictured)

Crews on station have 3-D printed two of three REM shields to investigate shielding options.

## RADIATION ENVIRONMENT ON THE SURFACE OF MARS IS NO WORSE THAN ISS FOR STAYS OF COMPARABLE DURATION


Radiation Assessment Detector (RAD) is currently operating on the Curiosity Rover.

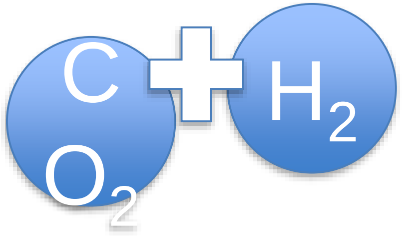


Hybrid Electronic Radiation Assessor (HERA) detects radiation levels and warns crews to take cover. Flew on EFT-1, will fly on EM-1, EM-2.

## BioManufacturing

**Rapid physico-chemical methods to convert $CO_2$ to an organic media that is used by microbes to produce mission-relevant products in space.**

Using rapid physical and chemical methods, we can expedite nature's refinery process to convert carbon dioxide to organic materials. These organic materials are then used by genetically engineered microbes to produce plastics, fibers, and other types of feedstock for in-space manufacturing.




Carbon Dioxide and Hydrogen in a physico-chemical processor → Microbial Medium → Growth System → Feedstock → Product

## BioNutrients

**Rapid, safe and reliable *in situ* production of needed dietary nutrients using minimal mass, power and volume for long duration missions.**

Developing hydratable, single-use packets that contain an edible growth medium and a food microbe that has been engineered to produce target nutrient(s) for human consumption. The packet is hydrated, allowed to grow for a short period, microbes deactivated, and the contents consumed.

Dehydrated single-use nutrient pack

Hydrated using existing hydration stations aboard ISS

Microbes deactivated and nutrients consumed

NASA