National Aeronautics and Space
Administration

HEO Status Report

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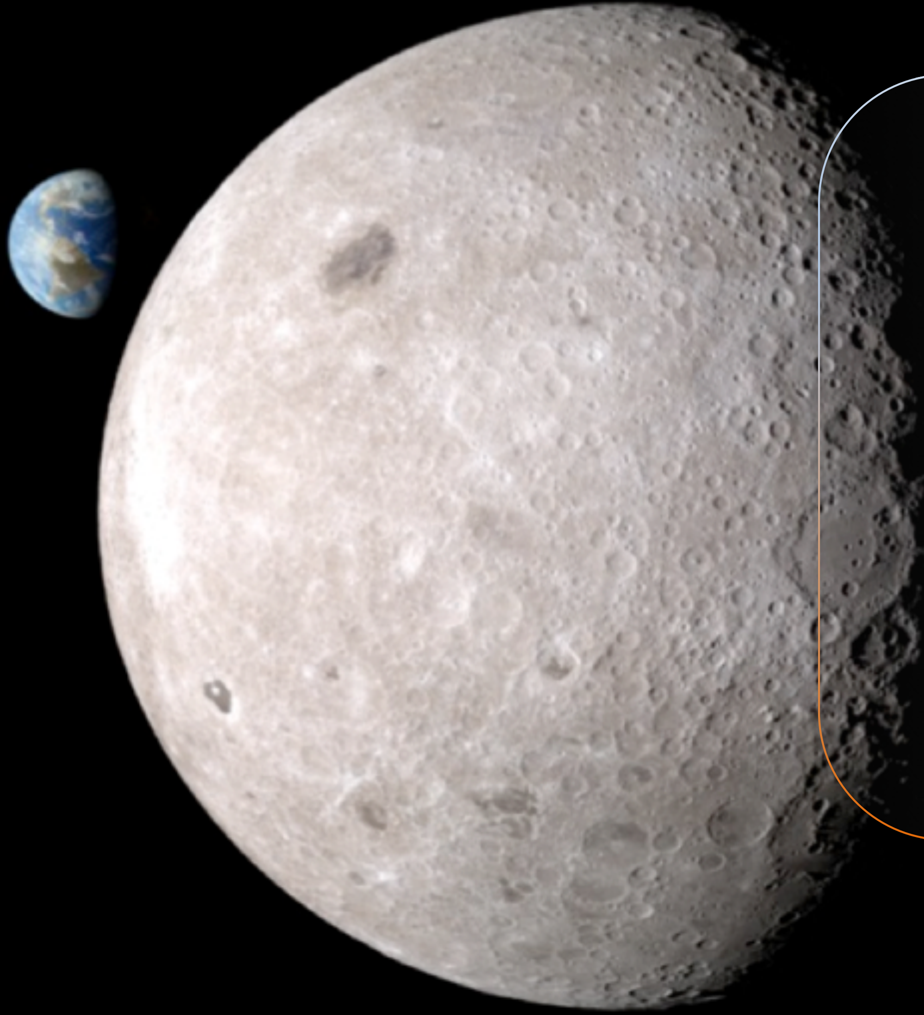
HOW ARE WE LEADING HUMAN SPACE EXPLORATION?



- Maximizing utilization of the International Space Station
- Actively promoting LEO commercialization
- Resolving the human health and performance challenges
- Expanding partnerships with commercial industry
- Growing international partnerships
- Building the critical Deep Space Infrastructure
- Enabling the capabilities to explore multiple destinations

LEADING THE MOVEMENT OF HUMANS INTO DEEP SPACE REQUIRES:
DOING, INFLUENCING, CONNECTING AND ORCHESTRATING

1. AGENCY
2. GOVERNMENT / PEOPLE
3. INDUSTRY
4. INTERNATIONAL PARTNERSHIP

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 cis-lunar space during ISS lifetime.

BENEFITS OF PUBLIC-PRIVATE PARTNERSHIP

In addition to financial investments, NASA helps its commercial partners:

- By sharing the knowledge NASA has matured through over 50 years of space flight allowing them to access unique expertise, goods, and services

- By making available valuable infrastructure and assets; thus providing emerging space companies with capabilities they could otherwise not afford

- By providing substantial early demand as an anchor customer

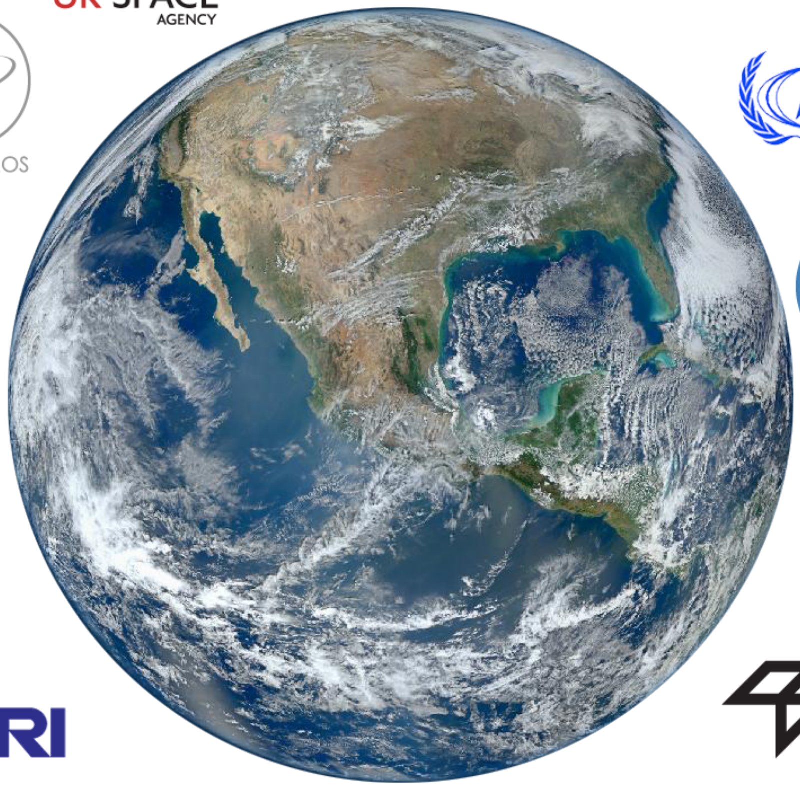
In return, an emerging space industry sparked by the initiative of private entrepreneurs:

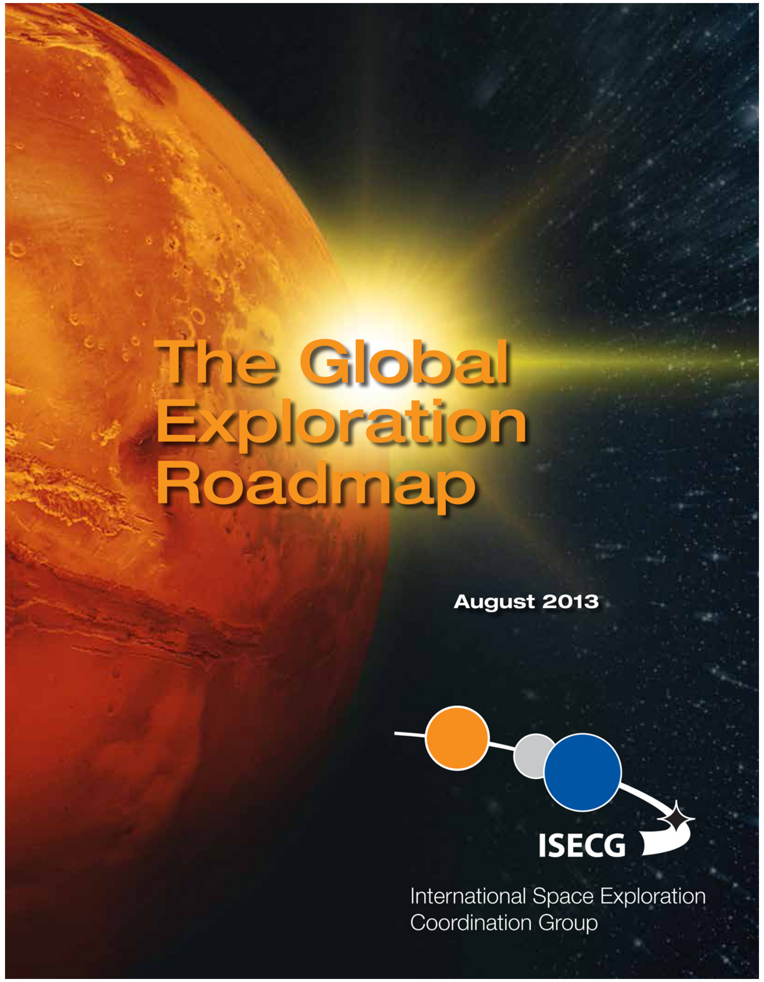
- Are dedicated to creating new markets for goods and services that will be integral to helping NASA and the nation continue expand the space economy and sustain deep space exploration.

- Are lowering the cost of launching cargo into space and transforming economic decision-making, therefore markets for services that once were cost-prohibitive are becoming increasingly realistic.

- Are regularly developing, testing, and implementing cutting-edge research, which yields potentially transformative solutions that can accelerate timelines, slash costs, or multiply science return.

INTERNATIONAL SPACE EXPLORATION COORDINATION GROUP
GLOBAL EXPLORATION ROADMAP





Global Exploration Roadmap – Version Three scheduled for release January 2018

DEEP SPACE SYSTEMS STANDARDS

- Establishing interoperability standards like international docking standards is critical to leading and orchestrating

- ISS partners, Space Communications, Next Step habitation and power and propulsion element BAA providers are all contributing to draft interoperability standards in several critical areas
  - International Avionics Data Interface Standard
  - International Communications System Standard
  - International Environmental Control Life Support Interoperability Standard
  - International Power System Standard
  - International Thermal System Interfaces Standard
  - International Rendezvous Standard
  - International External Robotic Interfaces Standard

- Plan is for even wider review at International Space Exploration Forum in March 2018
  - Government and state department level meeting
  - Sixty governments attend

FIRST STEP IN DEEP SPACE EXPLORATION

DEEP SPACE HABITATION SYSTEMS

Habitation Systems Elements

TODAY Space Station

FUTURE Deep Space

LIFE SUPPORT

Excursions from Earth are possible with artificially produced breathing air, drinking water and other conditions for survival.

Atmosphere Management

Water Management

Waste Management

Today – Space Station

- 42% O_2 Recovery from CO_2
- 90% H_2O Recovery
- < 6 mo mean time before failure (for some components)

Future – Deep Space

- 75%+ O_2 Recovery from CO_2
- 98%+ H_2O Recovery
- >30 mo mean time before failure

ENVIRONMENTAL MONITORING

NASA living spaces are designed with controls and integrity that ensure the comfort and safety of inhabitants.

Pressure O_2 & N_2

Moisture

Particles

Microbes

Chemicals

Sound

Today – Space Station

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

Future – Deep Space

- On-board analysis capability with no sample return
- Identify and quantify species and organisms in air & water

CREW HEALTH

Astronauts are provided tools to perform successfully while preserving their well-being and long-term health.

Monitoring

Exercise

Diagnostics

Treatment

Food Storage & Management

Today – Space Station

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

Future – Deep Space

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

EVA: EXTRA-VEHICULAR ACTIVITY

Long-term exploration depends on the ability to physically investigate the unknown for resources and knowledge.

Mobility

Life Support

Science and Exploration

Today – Space Station

- 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

Future – Deep Space

- 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

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. Monitoring, Tracking, Modeling, Mitigation	Node 2 crew quarters (CQ) with polyethylene reduce impacts of proton irradiation. Large multi-layer detectors & small pixel detectors – real-time dosimetry, environment monitoring, tracking, model validation & verification Bulky gas-based detectors – real-time dosimetry Small solid-state crystal detectors – passive dosimetry (analyzed post-mission)	Solar particle event storm shelter, optimized position of on-board materials and CQ Small distributed pixel detector systems – real-time dosimetry, environment monitoring, and tracking 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. Detection, Protection, Suppression, Cleanup	Large CO_2 Suppressant Tanks 2-cartridge mask Obsolete combustion prod. sensor Only depress/repress clean-up	Water Mist portable fire extinguisher Single Cartridge Mask Exploration combustion product monitor Smoke eater
LOGISTICS	Sustainable living outside of Earth requires explorers to reduce, recycle, reuse, and repurpose materials. 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
CROSS-CUTTING	Powerful, efficient, and safe launch systems will protect and deliver crews and materials across new horizons. Robotics, Power, Communication, Docking, Avionics, Autonomy & Software, Thermal, Materials	Minimal on-board autonomy Near-continuous ground-crew communications 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

CONSIDERATIONS

- Future of the National Lab
  - Role of the government in fostering R&D across private industry and non-NASA government agencies
- Re-use of on-orbit ISS elements
  - Many elements will have considerable structural life after 2028
  - Some systems, including the solar arrays, will need to be replaced by the end of the 2020s in order to maintain the current configuration
  - Maintenance levels less than originally anticipated
  - Value of the nation's investment is considerable

Element	Year Launched	+30 years
FGB/Node 1	1998	2028
US Lab	2001	2031
Node 2	2007	2037
Columbus/JEM	2008	2038
Node 3/Cupola	2010	2040
Truss segments	2000-2009	2030-2039

- Long-term NASA requirements for LEO research and utilization
  - NASA is currently assessing its LEO long term requirements and utilization needs

CONSIDERATIONS

- Transition indicators
  - Completion of exploration-related research and technology development requiring ISS
  - Demand from government and private industry including research and for-profit motivated activities, and whether that demand will support private LEO platforms and associated transportation costs
  - Establishment of cislunar Gateway capabilities and execution of missions beyond LEO

- Affordability in the larger HSF Exploration context
  - Need both low Earth orbit and Deep Space
  - Ideally private sector is largely supporting low Earth Orbit costs
    - Market Driven
    - Revenue positive

- Foreign Policy Considerations
  - US leadership in HSF
  - Other LEO space stations

- Timing of Low Earth Orbit non-government is a big question

CONSIDERATIONS

- Scope of public-private partnership models -- How to effect transition?
  - There is a large range of private partnership arrangements that could be considered
    - Proper role of the government vs. private industry needs to be explored
    - International Partner agreements
    - Ability for private industry to do business outside of government constraints
    - Scope of government needs for LEO in the long term

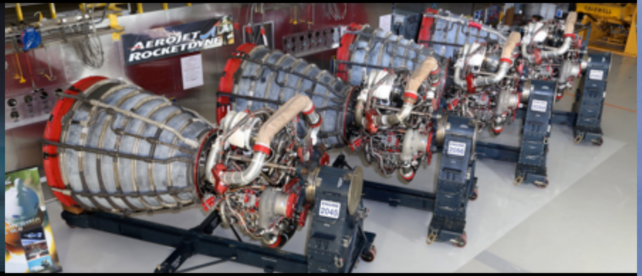
- ISS is <u>CRITICAL</u>
  - ISS is an asset for exploration development, commercial LEO, development, International leadership
  - We need to focus on using the assist and not focus solely on transition or see ISS as a liability
  - ISS is keeping the US a leader in spaceflight

DEEP SPACE EXPLORATION SYSTEMS
ORION – SLS – GROUND SYSTEMS

NASA tests ensure astronaut, ground crew safety before Orion launches

Orion processing continues in the Operations and Checkout Building High Bay for EM-1

SLS core stage pathfinder arrives at NASA Michoud



The four RS-25 engines that will power SLS

New Umbilical fitted for Mobile Launcher

Liquid Oxygen tanking operations begin at Launch Pad 39B

SLS FACILITIES AND FLIGHT HARDWARE FOR EM-1


ISPE STA
Test Stand


Intertank STA Test
Stand

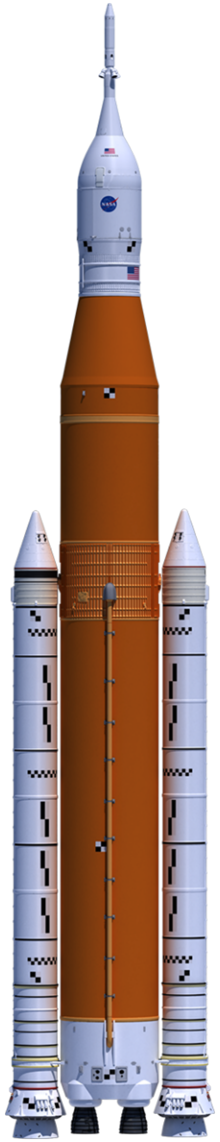

LO2 STA Test Stand


A-1 Core Stage Engine
Test Stand


LH2 STA Test Stand


Engine Section STA
Test Stand


B-2 Core Stage
Test Stand




ICPS


Core Stage LOX Tank


Core Stage Intertank


Core Stage Engines


Launch Vehicle
Stage Adaptor

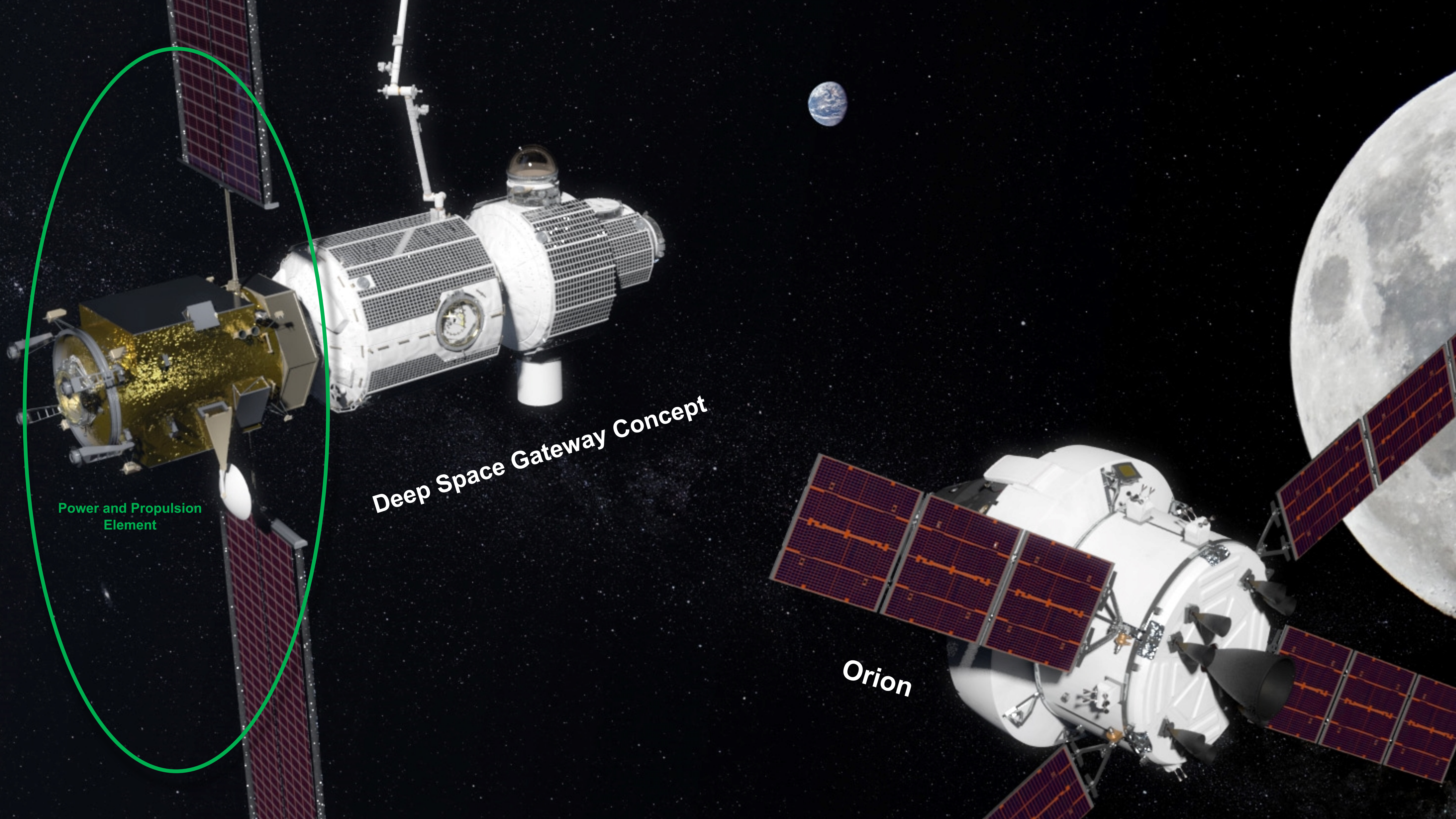

Core Stage
Hydrogen Tank


Orion Stage Adaptor


Core Stage Forward
Skirt


Booster Avionics


Booster Aft Skirt


Power and Propulsion
Element
Deep Space Gateway Concept
Orion

With creative leadership we can have a sustained human presence in low Earth orbit supported primarily by the private sector, and used by broad sectors of the economy while we advance human presence into the solar system.


NASA