NASA

Autonomy and the Gateway

Human-Robotic Systems and Operations

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NASA Autonomous Systems

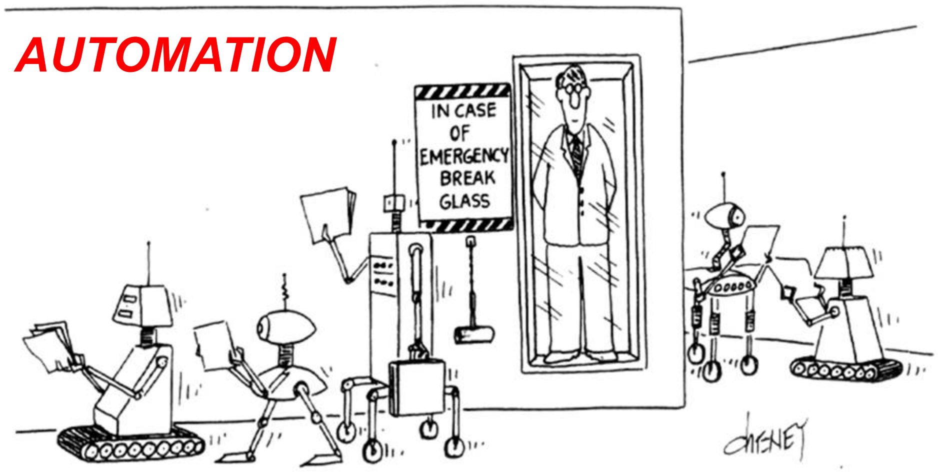
Systems Capability Leadership Team

- Serve as a **community of practice** in autonomous systems
- **Identify barriers** that impact the development and infusion of autonomy capabilities into mission systems
- Identify and **assess the NASA workforce** and facilities needed to advance autonomous systems
- **Recommend research and development** in autonomous systems technology for NASA
- **Recommend investment/divestment** to improve the use of autonomous systems in aeronautics (ARMD), human exploration (HEOMD), science (SMD), and space technology (STMD)

Structure

- Lead: Terry Fong (STMD)
- Deputy: Danette Allen (LaRC)
- Members: Center SMEs, relevant CLT leads, Mission Directorate reps

What is Autonomy?



VS.

- **Autonomy** is the ability of a **system** to achieve goals while operating independently of external control *(NASA Technology Roadmaps, TA 4: Robotics and Autonomous Systems, 2015).*
- A **system** is the combination of **elements** that function together to produce the capability required to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose (*NASA Systems Engineering Handbook, NASA SP-2016-6105 Rev 2*).
- **Autonomy technology** consists of the elements and methods required to build, test, certify, and operate an autonomous system.

What is NOT Autonomy?

Autonomy is NOT automation, but often relies on automation

- Automation is the automatically-controlled operation of an apparatus, process, or system using a pre-planned set of instructions
- Most deep-space robotic missions use automation (command seq)

Autonomy is NOT artificial intelligence (AI), but may make use of AI methods

- Machine learning (deep learning, reinforcement learning, etc.)
- Perception (object recognition, speech recognition, vision, etc.)
- Search, probabilistic methods, classification, neural networks, etc.

Autonomy is NOT necessarily about making machines "intelligent", "smart", or "unmanned"

- Autonomy is about making systems independent and self-reliant
- Systems can include humans as an integral element ("human-system integration", "human-autonomy teaming", etc.)

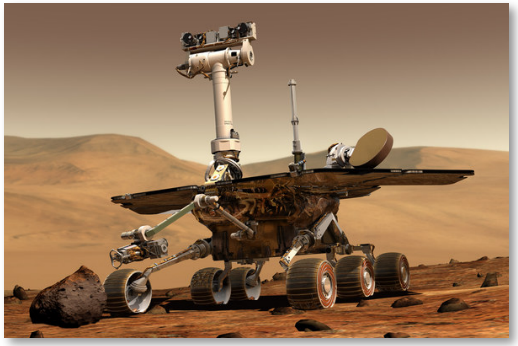
Autonomous Systems Taxonomy

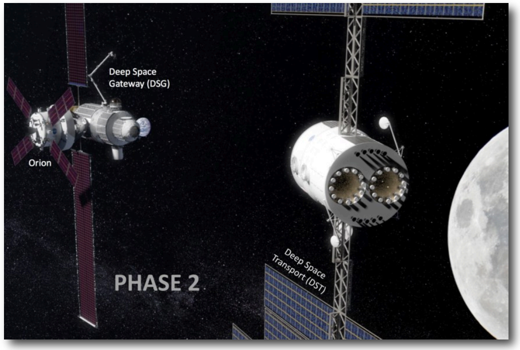
- **1.0 Situation and Self Awareness**
  - 1.1 Sensing and Perception
  - 1.2 State Estimation and Monitoring
  - 1.3 Knowledge and Model Building
  - 1.4 Hazard Assessment
  - 1.5 Event and Trend Identification
  - 1.6 Anomaly Detection
- **2.0 Reasoning and Acting**
  - 2.1 Mission Planning
  - 2.2 Activity and Resource Planning and Scheduling
  - 2.3 Motion Planning
  - 2.4 Execution and Control
  - 2.5 Fault Diagnosis and Prognosis
  - 2.6 Fault Response
  - 2.7 Learning and Adapting
- **3.0 Collaboration and Interaction**
  - 3.1 Joint Knowledge and Understanding
  - 3.2 Behavior and Intent Prediction
  - 3.3 Goal and Task Negotiation
  - 3.4 Operational Trust Building
- **4.0 Engineering and Integrity**
  - 4.1 Verification and Validation
  - 4.2 Test and Evaluation
  - 4.3 Operational Assurance
  - 4.4 Modeling and Simulation
  - 4.5 Architecture and Design

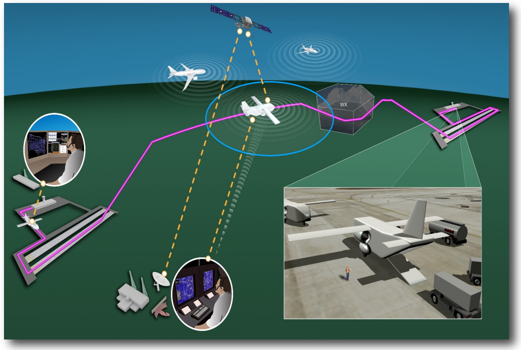
Why autonomy?

Autonomy is needed …

- When the cadence of decision making exceeds **communication constraints** (delays, bandwidth, and communication windows)
- When **time-critical decisions** (control, health, life-support, etc) must be made on-board the system, vehicle, etc.
- When decisions can be better made using **rich on-board data** compared to limited downlinked data (e.g., adaptive science)
- When local decisions **improve robustness** and **reduces complexity** of system architecture
- When autonomous decision making can **reduce system cost** or **improve performance**
- When **variability in training, proficiency**, etc. associated with manual control is unacceptable







Where can NASA use Autonomy?

EARTH LAUNCH AND LANDING SYSTEMS

- Launch Vehicles
- Launch Abort Systems
- Entry, Descent and Landing

EARTH ATMOSPHERIC SYSTEMS

- Unmanned Aerial Systems
- Vehicle Mission Safety
- Vehicle Performance Enhance
- Human-machine teaming
- National Airspace Management
- Distributed Large-scale Collaborative Systems

GROUND SYSTEMS

- Mission Operations
- Visualization and Interaction
- Robotic Inspection and Repair
- Propellant/Commodity Loading

ROBOTIC EARTH-ORBITING SYSTEMS

- Formation Flying
- Constellations and Swarms
- Rendezvous and Docking
- On-Orbit Servicing
- In-Space Assembly
- In-Space Manufacturing
- Instrument Data Analysis
- Sensor Web

HUMAN EARTH-ORBITING SYSTEMS

- Life Support
- Rendezvous and Docking
- On-Orbit Servicing
- Visualization and Interaction
- Robotic Assistants
- Mission and Data Analysis
- In-space Manufacturing
- In-space Assembly

ROBOTIC SPACE SYSTEMS

- Planetary Ascent Vehicles
- Rendezvous and Docking
- Entry, Descent & Landing
- In Situ Access
- Sample Collection
- Orbital Navigation
- Instrument Data Analysis
- In Situ Resource Utilization

HUMAN SPACE SYSTEMS

- Planetary Ascent Vehicles
- Life Support
- Rendezvous and Docking
- Entry, Descent & Landing
- Surface Transport
- Robotic Assistants
- Mission and Data Analysis
- In Situ Resource Utilization

Human Exploration

From Earth to the Moon and Mars

Now

Using the International Space Station

2020s

Operating in the Lunar Vicinity (proving ground)

After 2030

Leaving the Earth-Moon System and Reaching Mars Orbit

Phase 0

Continue research and testing on ISS to solve exploration challenges. Evaluate potential for lunar resources. Develop standards.

Phase 1

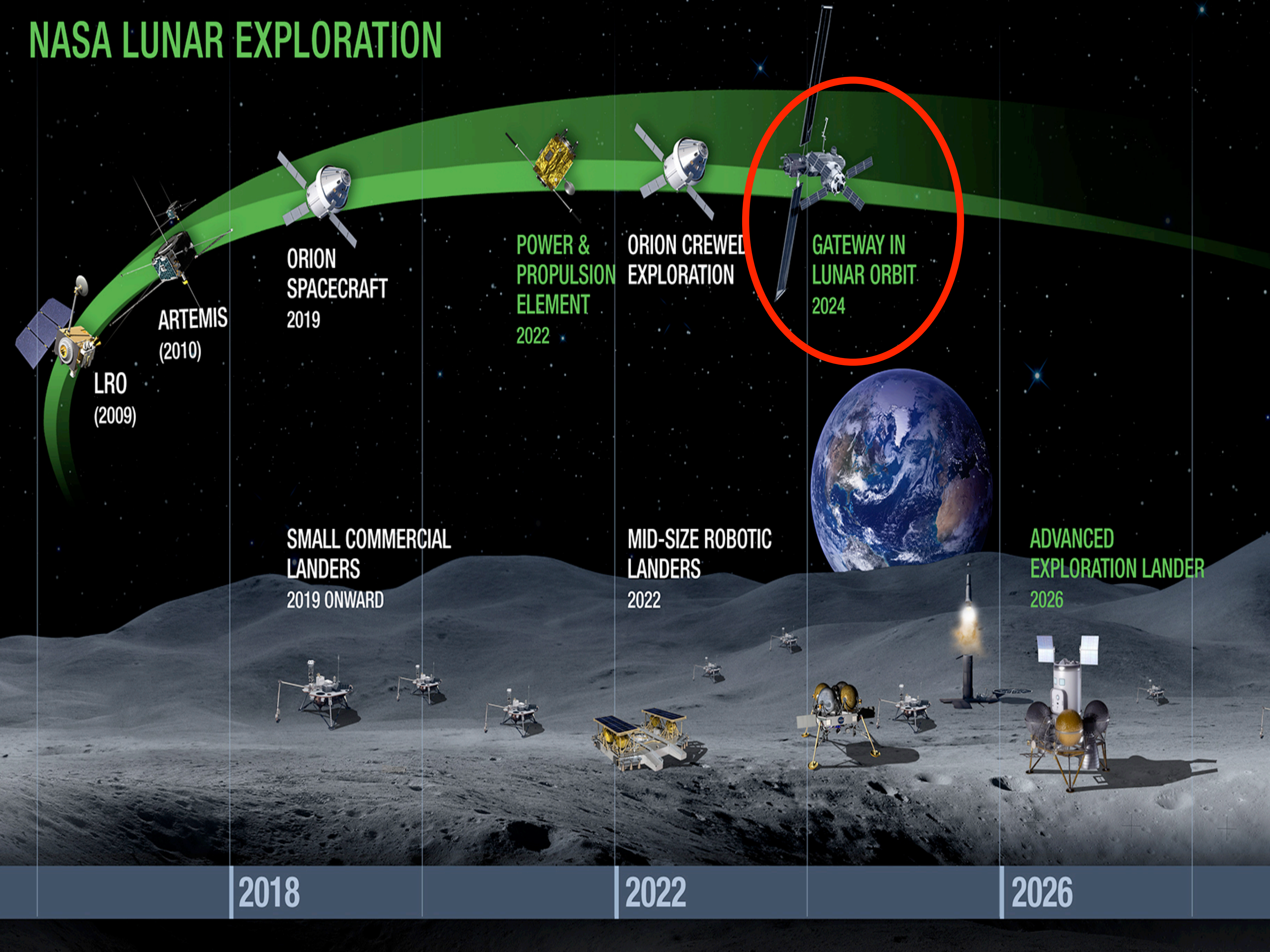
Begin missions in cislunar space. Build Deep Space Gateway. Initiate assembly of Deep Space Transport.

Phase 2

Complete Deep Space Transport and conduct yearlong Mars simulation mission.

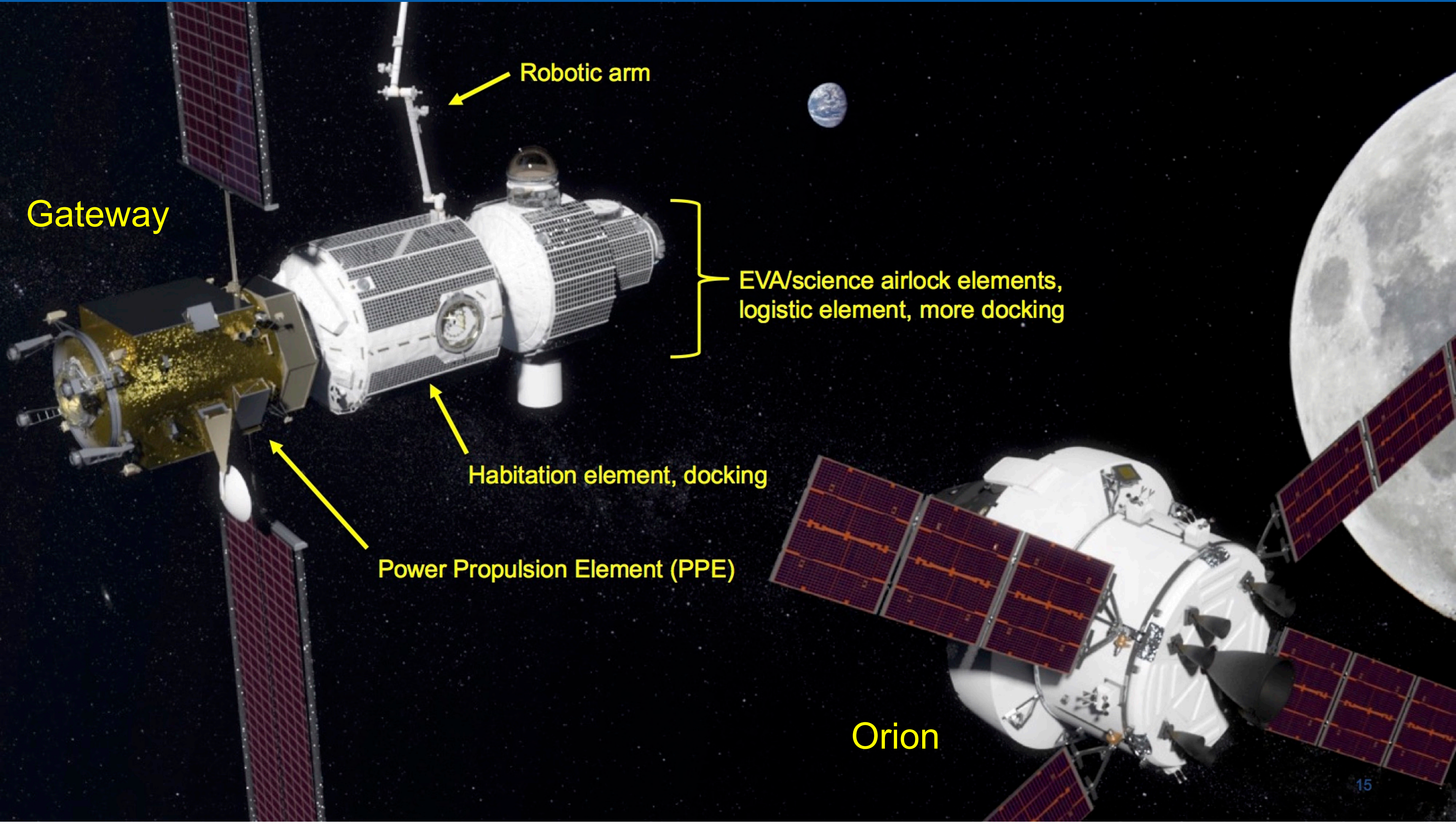
Phases 3 and 4

Begin sustained crew expeditions to Martian system and surface of Mars.



NASA LUNAR EXPLORATION
LRO
(2009)
ARTEMIS
(2010)
ORION
SPACECRAFT
2019
POWER &
PROPULSION
ELEMENT
2022
ORION CREWED
EXPLORATION
GATEWAY IN
LUNAR ORBIT
2024
SMALL COMMERCIAL
LANDERS
2019 ONWARD
MID-SIZE ROBOTIC
LANDERS
2022
ADVANCED
EXPLORATION LANDER
2026
2018
2022
2026

Gateway Initial Configuration (Notional)



Gateway Initial Elements

Power and Propulsion Element (PPE)

- **First gateway capability** targeted for launch readiness in **2022**
- Power to gateway and externally accommodated elements
- Attitude control, orbit maintenance, and potential uncrewed orbit change
- Communications with Earth, space-to-space communications, and radio frequency relay capability

Habitation

- Provides habitable volume & short-duration crew life support
- Can be docked to the PPE, other elements, and visiting vehicles
- Offers attach points for external robotics, external science payloads, etc.
- Accommodations for crew exercise, science/utilization and stowage

Logistics

- Deliver cargo and supplies to enable extended crew mission durations
- Support science utilization, exploration technology demonstrations, potential commercial utilization

GATEWAY DEVELOPMENT

Establishing leadership in deep space and preparing for exploration into the solar system

FOUNDATIONAL GATEWAY CAPABILITIES

2022	2023	2024+	
50 kW-class Power & Propulsion Element	Habitation and Utilization	Logistics and Robotic Arm	Airlock

These foundational gateway capabilities can support multiple U.S. and international partner objectives in cislunar space and beyond.

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CAPABILITIES

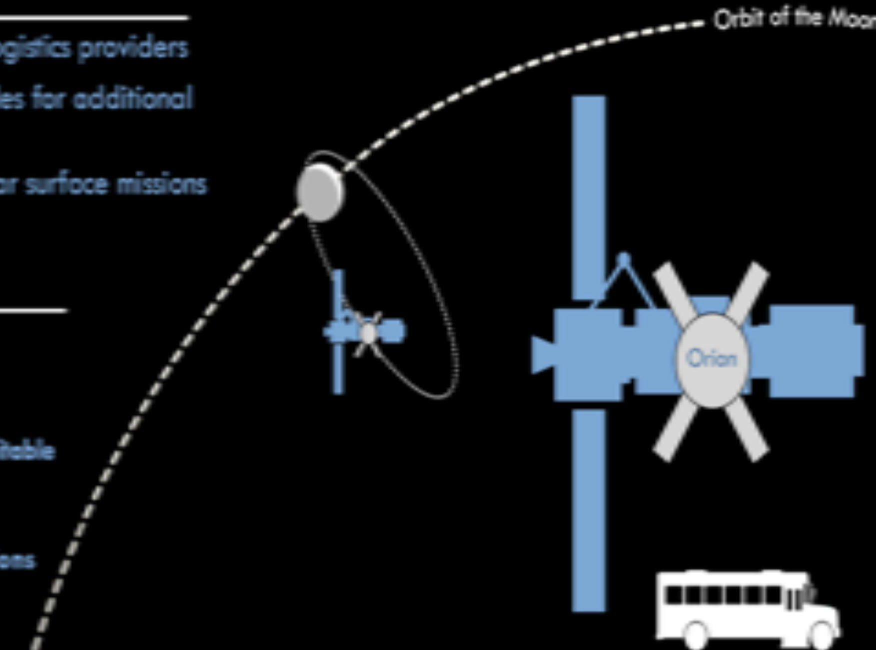
- Supports exploration, science, and commercial activities in cislunar space and beyond
- Includes international and U.S. commercial development of elements and systems
- Provides options to transfer between cislunar orbits when uncrewed
- External robotic arm for berthing, science, exterior payloads, and inspections

OPPORTUNITIES

- Logistics flights and logistics providers
- Use of logistics modules for additional available volume
- Ability to support lunar surface missions

INITIAL SCOPE

- 4 Crew Members
- At least 55 m^3 Habitable Volume
- 30 Day Crew Missions
- Up to 75mt with Orion docked



Bus shown for scale

Gateway Initial Scope

Crewed Missions

- 4 astronauts for 30 days
- Crew transit to/from Gateway using Orion
- Mission ops will likely be quite similar to ISS
- 55+ m^3 habitable volume (ISS has 388 m^3 habitable volume)
- May involve a variety of science and technology demo activities
- Likely high-bandwidth continuous communications with limited delay (10-30 sec round-trip)

Uncrewed Missions

- 92% of the year
- Will need a hybrid of ISS and robotic mission ops
- External and internal (tbd) robotics
- May involve a variety of science and technology demo activities
- Likely intermittent, high-bandwidth communications with limited delay (10-30 sec round-trip)

Gateway Utilization

Commercial

- Developing overall commercialization strategy
- RFI on commercial uses of a gateway (early Summer 2018)

International

- Developing strategy to involve international, ISS and non-ISS partners
- ESA could make major contributions: transportation and infrastructure

Science and Research

- Identifying potential science opportunities
- Assessing how gateway infrastructure can support future investigations
- Considering findings from Gateway science workshop (Feb 2018)

Technology

- **Evolve** initial capabilities or **enable** new capabilities for exploration
- Stimulate the development of commercial capabilities for cislunar space
- Evaluating **Gateway Technology Utilization RFI** (closed June 11)

Autonomous Crew Medical Operations

Tech Demo Concept:

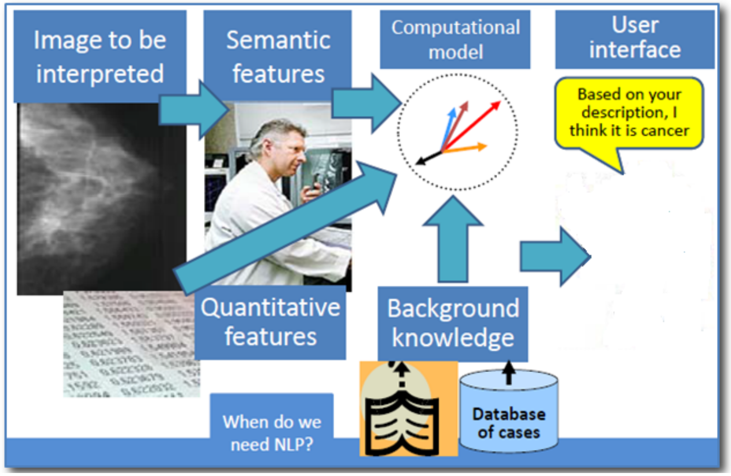
- Astronaut performs ultrasound self-exam and diagnosis without assistance from mission control. Requires decision support software for planning, conducting, and analyzing medical data.

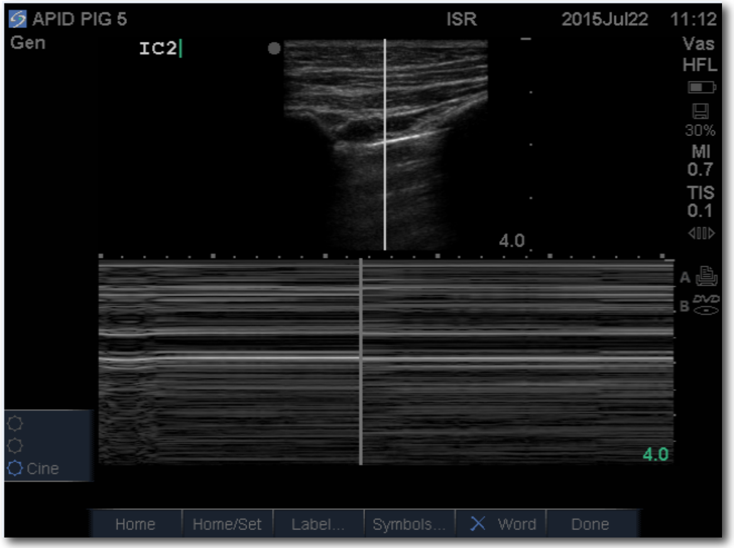
Relevance:

- Will enable better contingency (loss of comm) robustness for crew health
- Will enable greater crew independence for deep-space missions

Gateway Requirements:

- Requires medical device data, vehicle data and crew self scheduling to be integrated
- Infusion of HRP Exploration Medical Capability, GCD AMO, and AES ASO technology





pulmonary ultrasound

Autonomous Crew In-Flight Maintenance

Tech Demo Concept:

- Astronaut performs inspection and repair of exercise equipment (as an example subsystem) without assistance from ground. Requires decision support software for planning, conducting, and execution of IFM procedures.

Relevance:

- Will enable better contingency (loss of comm) robustness for IFM
- Will enable greater crew independence from ground control for deep-space missions

Gateway Requirements:

- Requires equipment device data, vehicle data and crew self scheduling to be integrated
- Infusion of AES ASO technology

Exercise treadmill servicing

Carbon Dioxide Removal Assembly maintenance

IVA Payload Support Robot

Tech Demo Concept:

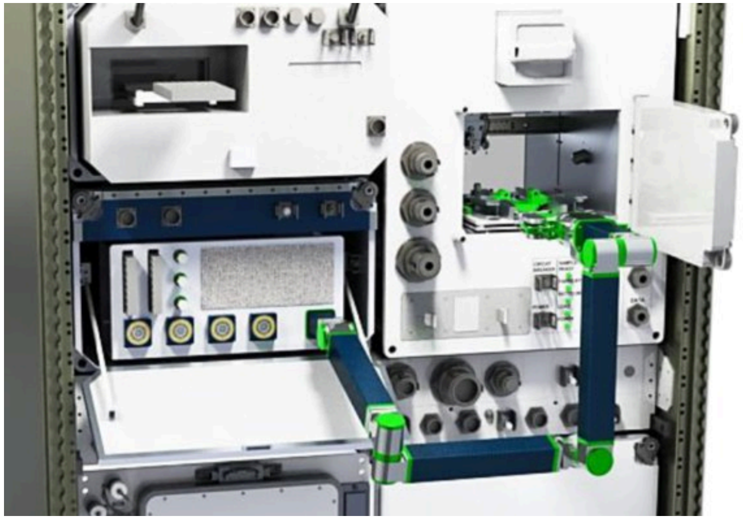
- IVA robot autonomously conducts IVA payload operations independent of crew and/or during uncrewed periods. Could be limited to specific “work area” and tasks.
- Example: robot initiates an experiment, periodically monitors and manipulates, perform shutdown, etc.

Relevance:

- Manage payloads without crew
- SBIR development could evolve into Gateway payload

Gateway Requirements:

- IVA robots need to be integrated into Gateway communications, power, and data systems
- Infusion of autonomous caretaking tech from AES ASO, AES LR, and GCD ISAAC (proposed) projects



MANTIS arm concept (Tethers Unlimited)

IVA Caretaking Robot

Tech Demo Concept:

- IVA robot autonomously performs habitat caretaking independent of crew and/or during uncrewed periods
- Examples: (1) prepare for crew ingress after uncrewed period, (2) isolate & respond to anomaly, (3) routine monitoring

Relevance:

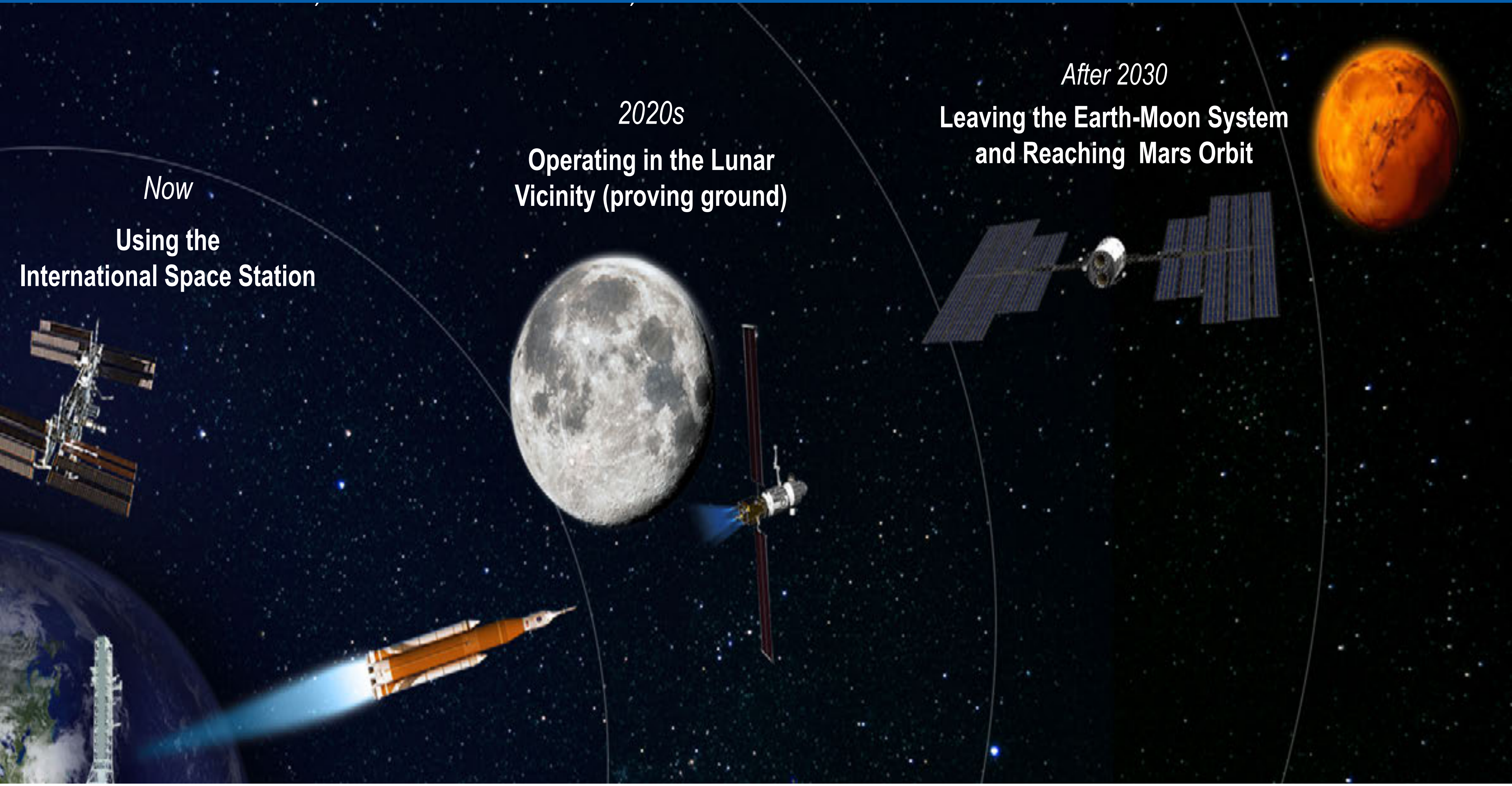
- Provides capability to ready the Gateway for crew arrival. Similarly, robotic systems may be used to “clean up” after crew.

Gateway Requirements:

- IVA robots need to be integrated into Gateway communications, power, and data systems
- Supports infusion of autonomous IVA caretaking tech from AES ASO, AES LR, GCD ISAAC (proposed), and STRI “SmartHabs” projects

Astrobee free-flying robot (under development)

Questions?



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