The Gateway

Enabling infrastructure for a new era of lunar robotics

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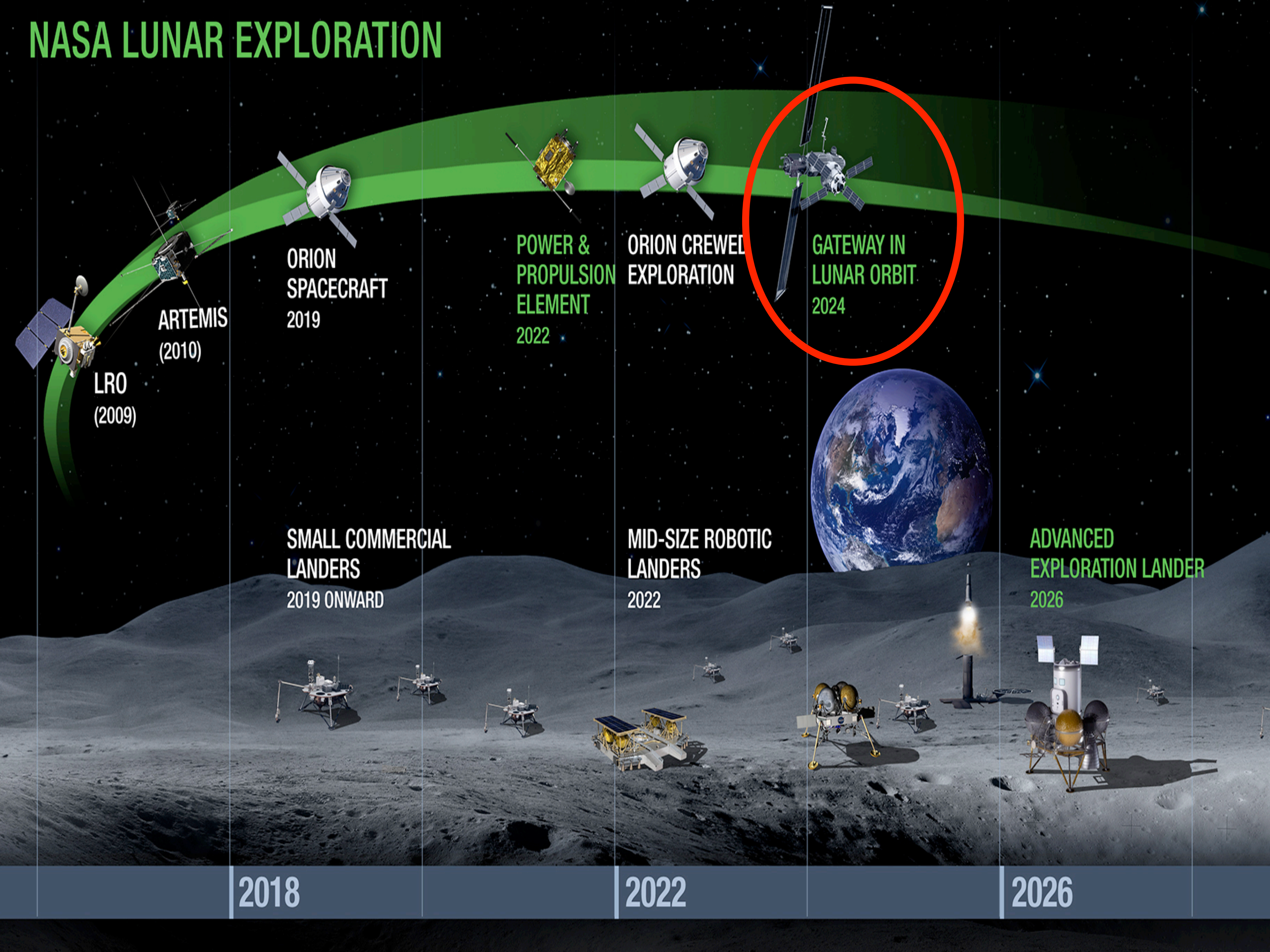
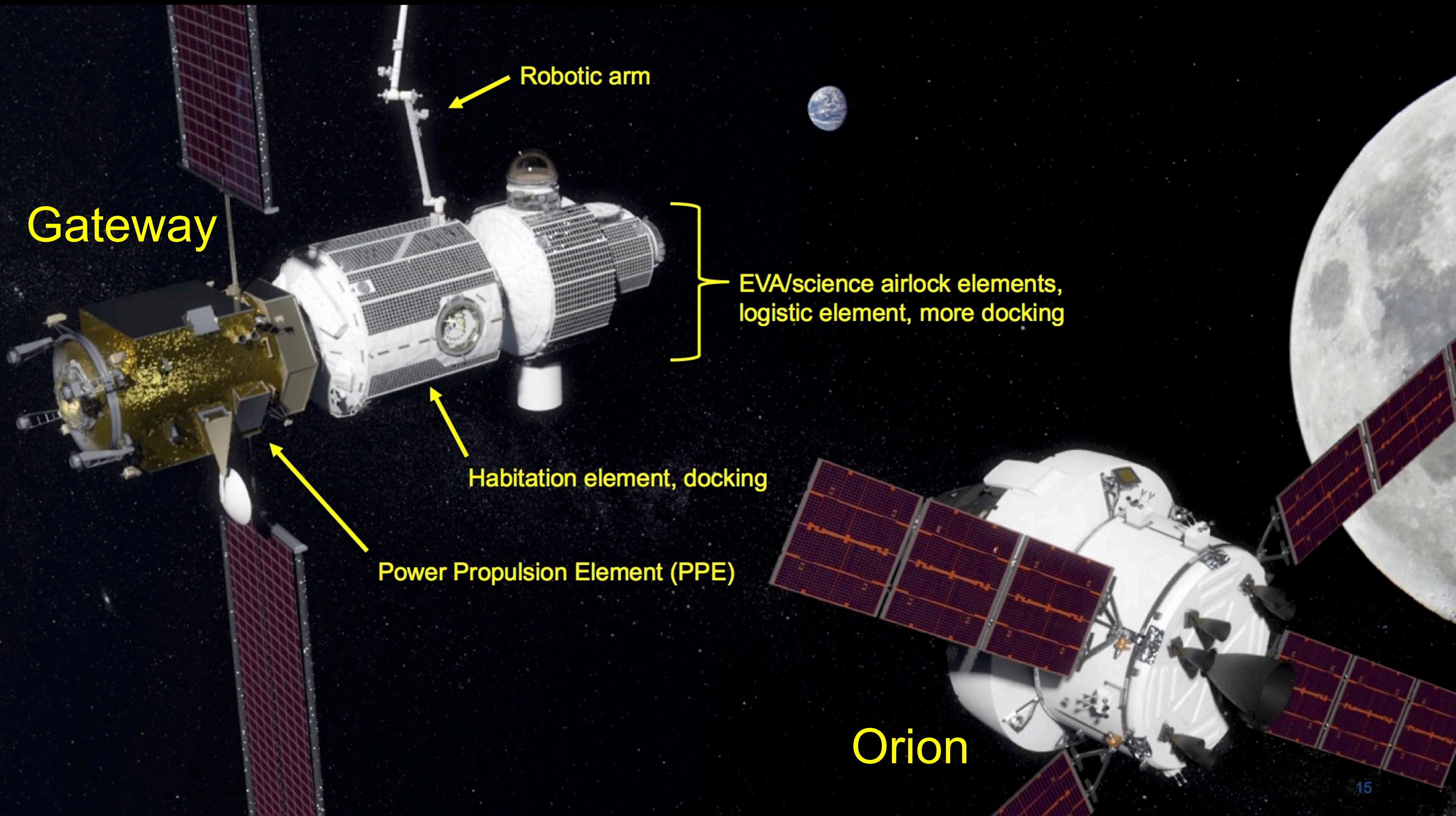


NASA LUNAR EXPLORATION
LRO
(2009)
ARTEMIS
(2010)
ORION
SPACECRAFT
2019
POWER &
PROPULSION
ELEMENT
2022
ORION CREWED
EXPLORATION
GATEWAY IN
LUNAR ORBIT
2024
SMALL COMMERCIAL
LANDERS
2019 ONWARD
MID-SIZE ROBOTIC
LANDERS
2022
ADVANCED
EXPLORATION LANDER
2026
2018
2022
2026

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

- Habitable volume and short-duration (~4 weeks initially) 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.

CAPABILITIES

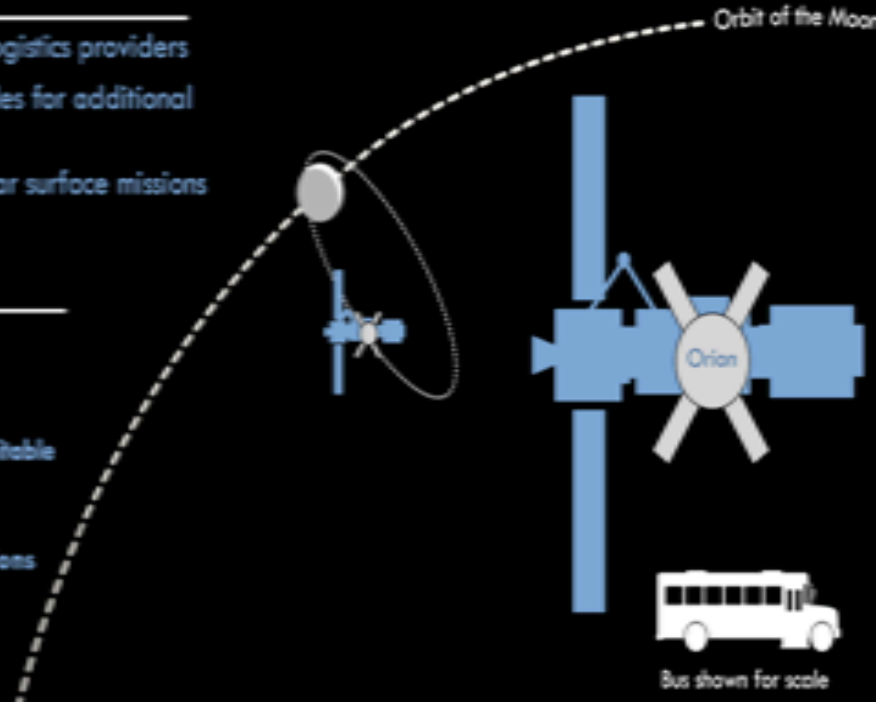
- Supports exploration, science, and commercial activities in cislunar space and beyond
- Includes international and U.S. commercial development of elements and systems
- Provides options to transfer between cislunar orbits when uncrewed
- External robotic arm for berthing, science, exterior payloads,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



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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)

Lunar Robotics Support

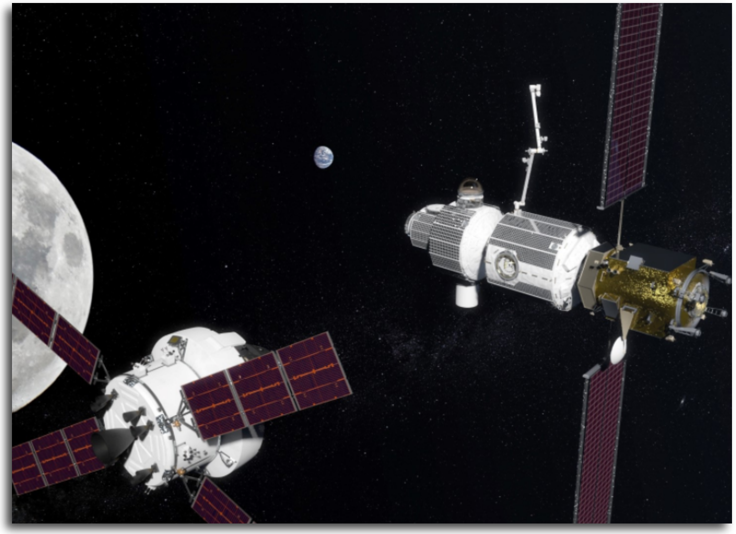
The Gateway could provide infrastructure for lunar robotics

- **Communications relay**: provide (or increase) link availability and bandwidth to the surface – particularly polar regions and the far side
- **"Orbital computing"** (space equivalent of "cloud computing")
  - Off-load processing from rover – potentially much higher performance
  - Off-board storage from rover – for later triage, downlink, or retrieval
- **Mapping from orbit**: provide site maps
- **Positioning** & **timing**: assist rover localization
- **Power beaming**: provide supplementary and survival energy
- **Remote sensing**: complement surface level data collection
- **Sample return cache**: intermediate location for high-grading
- … and more …

Gateway Technology Utilization RFI

Cloud computing on the Gateway

- Gateway provides "cloud computing" services for lunar missions (orbital or surface) systems, such as robots
- Scalable, on-demand data processing and storage, possibly with auto fall-over for high reliability
- Prototype for deep space missions



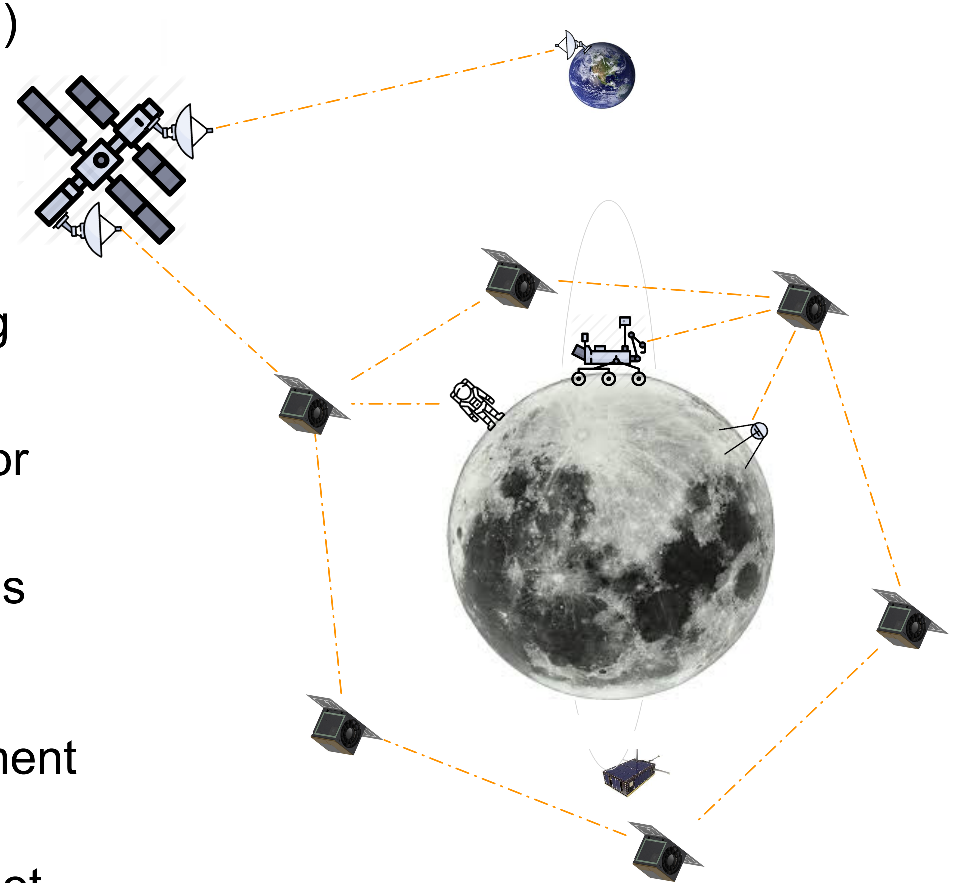
Gateway design requirements

- Need to design computing to be usable as on-demand service (reuse cloud computing standards?)
- Might need more on-board computing than is currently baselined
- Requires data communications (not necessarily continuous) between the Gateway and mission systems

Gateway Technology Utilization RFI

On-demand orbital infrastructure

- Gateway deploys a group (swarm) of small-sats to provide **orbital infrastructure services** to lunar surface missions
- Possible services: comm-relay, orbital imaging, positioning, timing
- Scalable, on-demand support
- Potentially low-cost (particularly for short duration cubesats)
- Prototype for deep-space missions



Gateway design requirements

- Need to design small-sat deployment system
- Requires data communications (not necessarily continuous) between the Gateway and small-sats

Lunar Robotics ConOps

Many ways to conduct lunar robotic missions

- Astronaut performs real-time, **manual control** (“joysticking” or “teleop”)
- Astronaut performs **supervisory control** (robot has some autonomy)
- Mission control performs **manual** or **supervisory control** while Astronaut performs **real-time monitoring** and/or data triage
- Astronaut and mission control **time-share** the robot
- Astronaut operates robot **while at Gateway** and Mission control operates robot **during Gateway dormant** periods
- Gateway provides **telerobotic mission support**
- **… and more …**

Many variables to consider

- Communication links (availability, bandwidth, latency)
- Mission requirements (activities, timelines, training, etc)
- Orbit (Lagrange points, halo, polar, period, amplitude range, etc.)
- System capabilities (astronauts, ground control, rover, spacecraft)
- Time phasing, schedules, etc.

State-of-the-Art in Space Telerobotics

Human Exploration Telerobotics

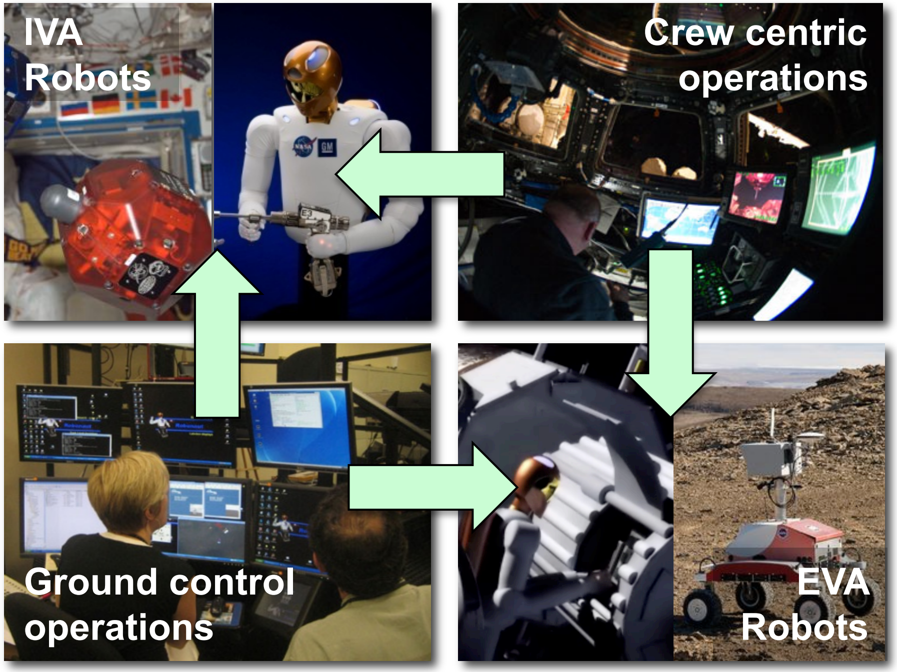
- NASA STMD (2010 – present)
- Mature space telerobotics technology to TRL 7
- Use ISS for testing

Ground control ops

- Mission control remotely operates robot on ISS
- Off-load routine & tedious work from crew to ground control
- In-flight maintenance, repetitive tasks, remote monitoring

Crew centric ops

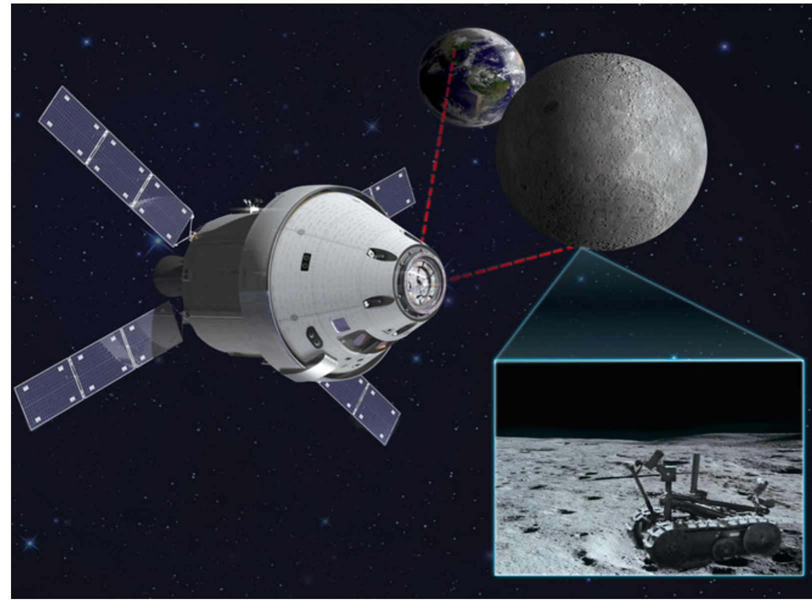
- Astronauts remotely operate planetary rovers from inside ISS
- Survey, deployment, inspection

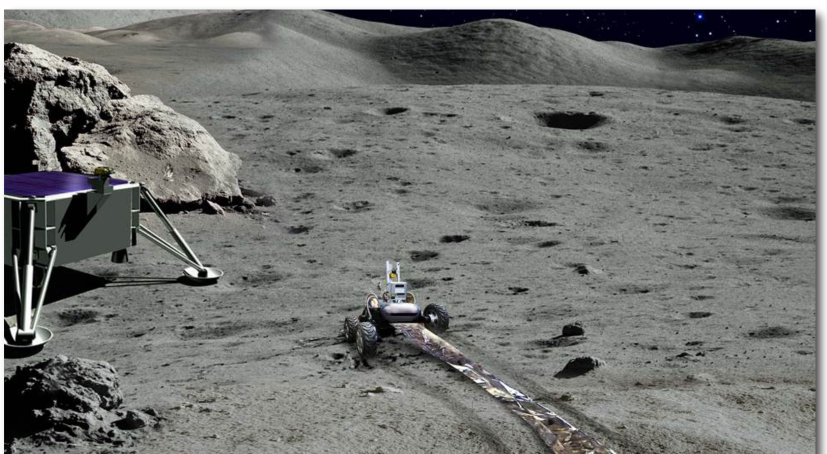


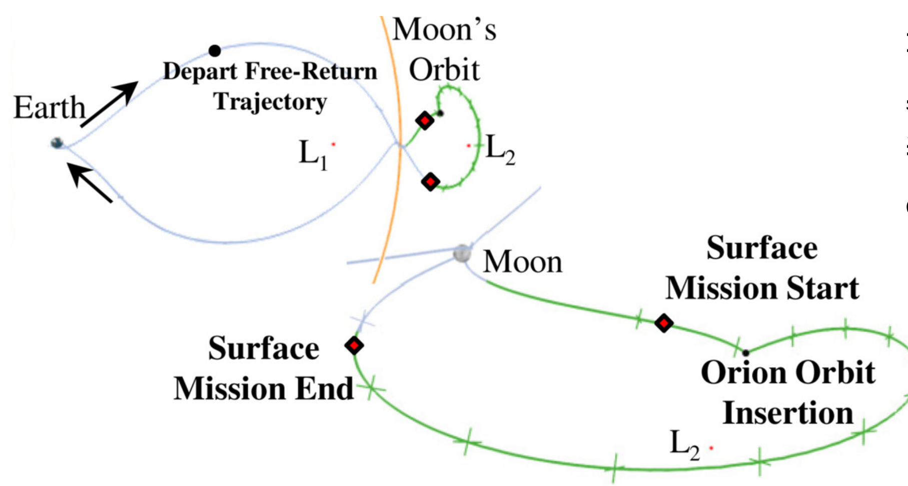
Lunar Mission Concept (2011)

Orion at Earth-Moon L2 Lagrange

- Astronaut remotely operates lunar rover from orbiting spacecraft – ***AVATAR in real-life!***
- Spacecraft orbiting 60,000 km beyond lunar farside
- High-bandwidth, low-latency data communication between spacecraft and surface robot







Credit: (Lockheed Martin / LUNAR)

Lunar Mission Simulation (2013)

"Surface Telerobotics" Project

- Simulation of the "Orion at Earth-Moon L2 Lagrange" concept
- Astronauts in the International Space Station (ISS)
- K10 planetary rover at NASA Ames
- Data comm via satellite relay with short delay (**750 msec round-trip**)
- Asynchronous bandwidth (**3 Kbps downlink, 800 Kbps uplink**)

ISS Expedition 36 testing

June 17, 2013 – **C. Cassidy**, survey

July 26, 2013 – **L. Parmitano**, deploy

Aug 20, 2013 – **K. Nyberg**, inspect

SURVEY

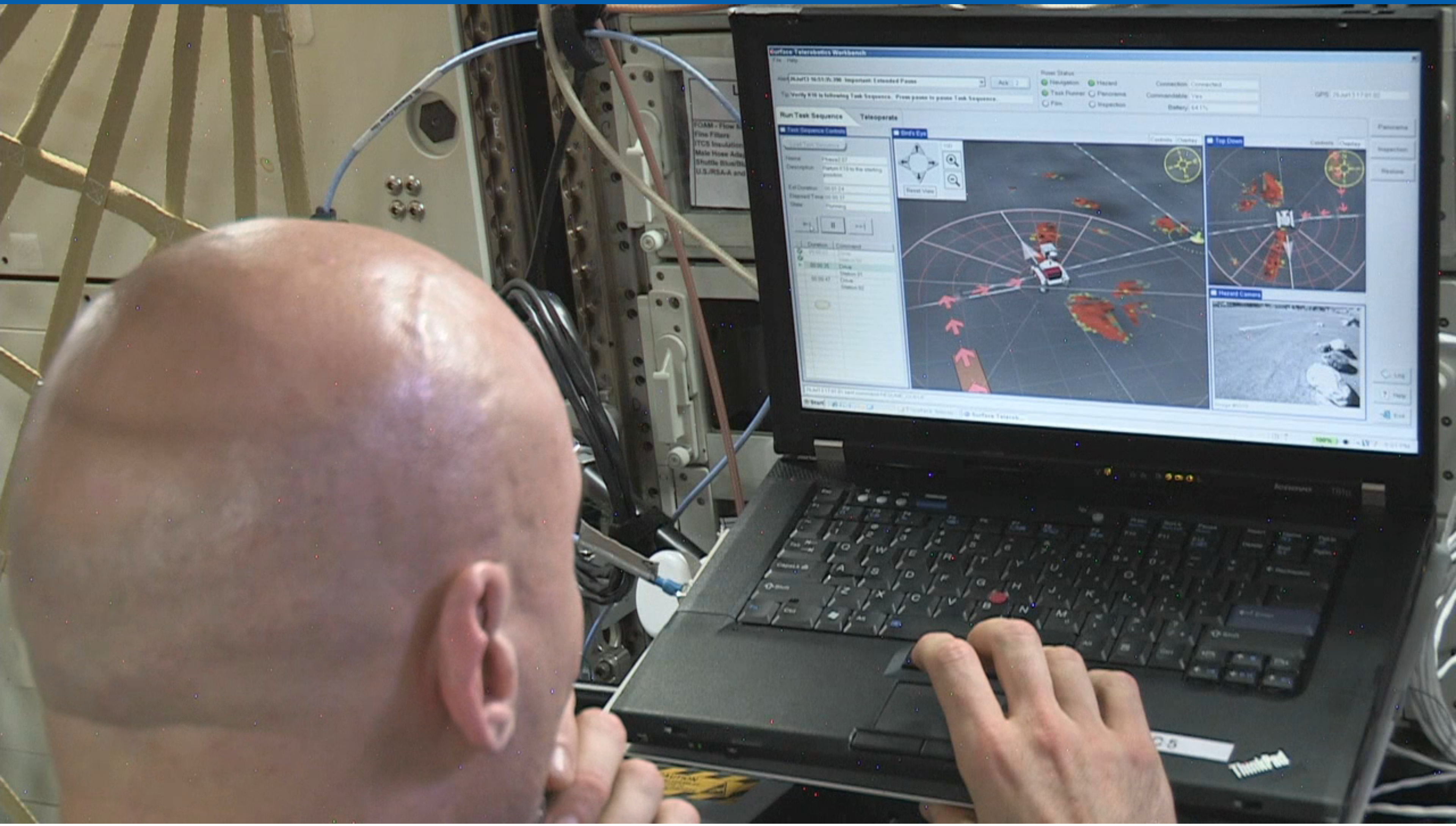
DEPLOY

INSPECT

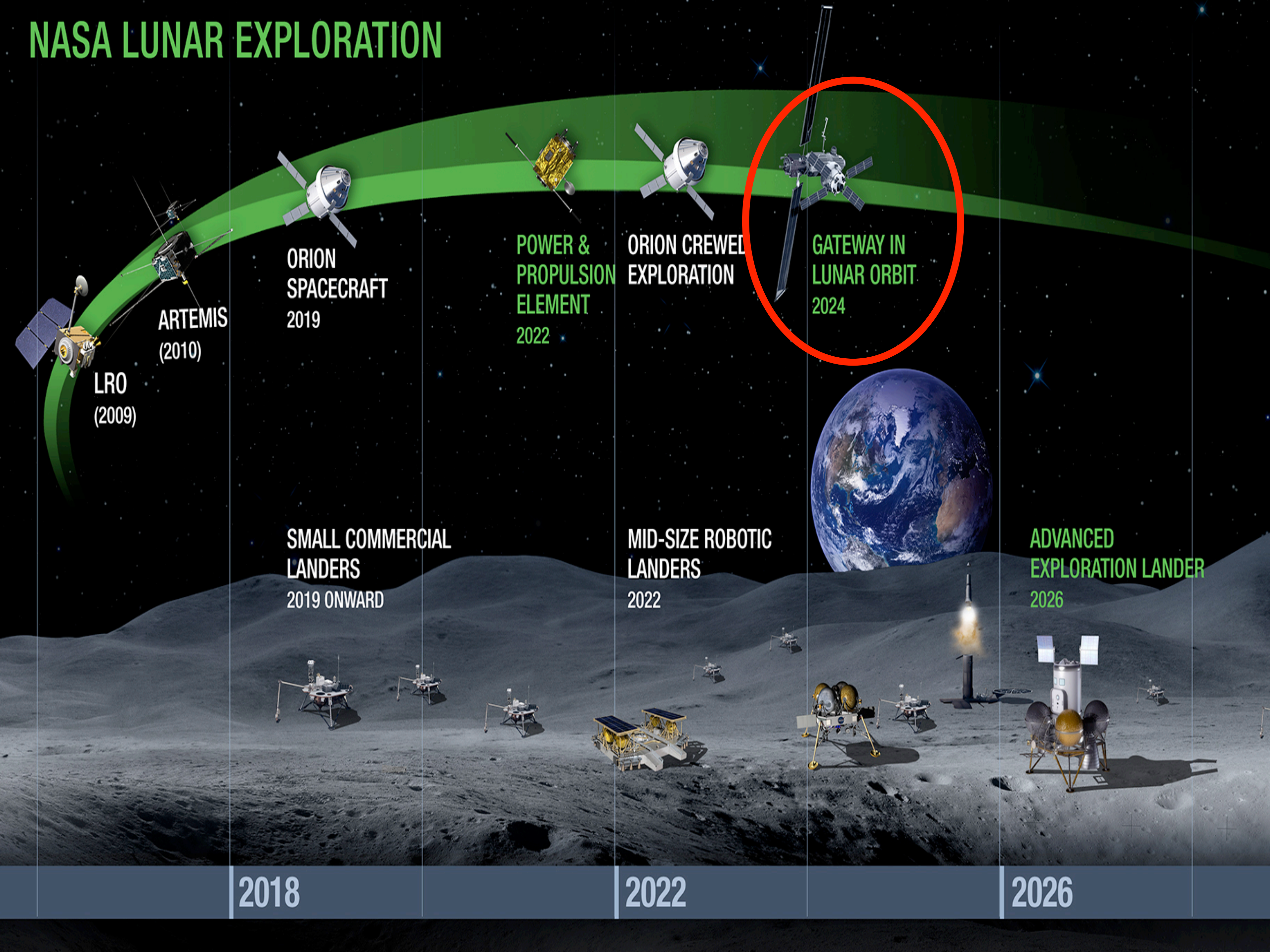
- **Human-robot mission sim**: site survey, telescope deployment, and inspection
- **Telescope proxy**: Kapton polyimide film roll (no antenna traces, electronics, or receiver)
- **3.5 hr per crew session** ("just in time" training, system checkout, ops, & debrief)
- **Robot ops**: manual control (discrete commands) and supervisory control (task sequence)

SPACESTATION
LIVE

Crew Control of a Planetary Rover



It is FEASIBLE for crew to remotely operate a planetary rover from orbit
(depending on conops, communications, control mode, environment, risk tolerance, rover capabilities, task, training, user interface and many, many other factors …)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Some Key Questions

How can the Gateway most benefit lunar robotic missions?

- Including astronauts in robot / science operations?
- Providing enabling infrastructure and services?

Should astronauts on the Gateway operate lunar rovers?

- Constrain missions to only operate when astronauts are available?
- Would “real-time operations” unacceptably increase mission risk?

What additional studies, development and testing are needed?

- What data do we need to develop future lunar robotic missions?
- How can we best obtain and validate this data?