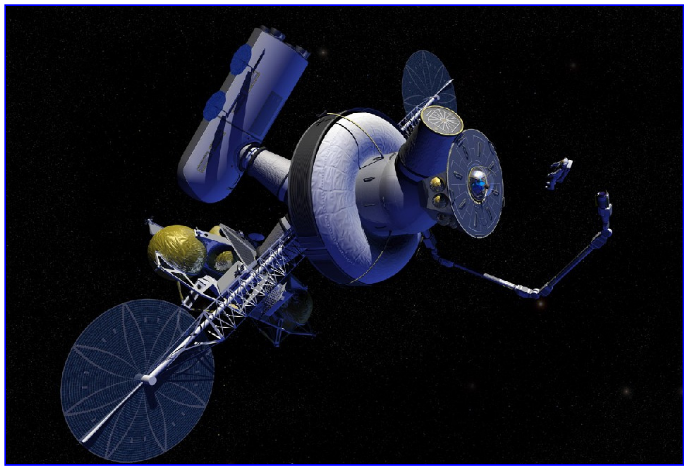
The Lunar L1 Gateway Concept:

Supporting Future Major Space Science Facilities



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Concepts for Optimized Human/Robotic Support of Advanced Science Facilities

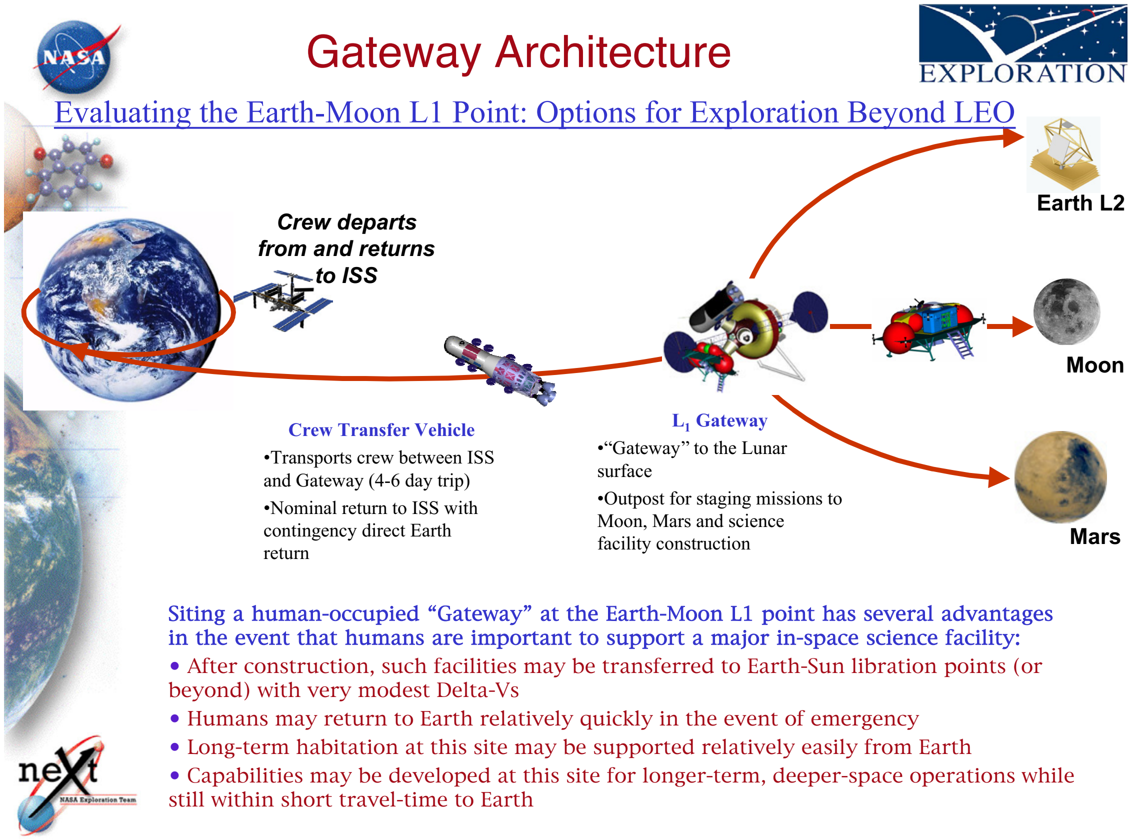
The Challenge :

Ambitious science facilities, such as post-NGST astronomical telescopes, will be extremely difficult to deploy, construct, rescue, service, and repair in space without sophisticated capabilities for manipulation. Such capabilities might include advanced robots, autonomous or remotely-operated systems, and/or humans on-site.

The Goals of This Study:

We report here on a series of ongoing studies to evaluate alternative architectures for future space science facilities and how robots, humans, and autonomous systems might be optimally used to support them.

This presentation outlines one scenario -- a “Gateway” at the Earth-Moon L1 point for supporting multiple options beyond Low Earth Orbit -- plus our process for evaluating human/robotic activities to construct telescopes.


Gateway Architecture
EXPLORATION
Evaluating the Earth-Moon L1 Point: Options for Exploration Beyond LEO
Crew departs from and returns to ISS
Earth L2
Moon
Mars
Crew Transfer Vehicle
•Transports crew between ISS and Gateway (4-6 day trip)
•Nominal return to ISS with contingency direct Earth return
L_1 Gateway
•"Gateway" to the Lunar surface
•Outpost for staging missions to Moon, Mars and science facility construction
Siting a human-occupied "Gateway" at the Earth-Moon L1 point has several advantages in the event that humans are important to support a major in-space science facility:
• After construction, such facilities may be transferred to Earth-Sun libration points (or beyond) with very modest Delta-Vs
• Humans may return to Earth relatively quickly in the event of emergency
• Long-term habitation at this site may be supported relatively easily from Earth
• Capabilities may be developed at this site for longer-term, deeper-space operations while still within short travel-time to Earth
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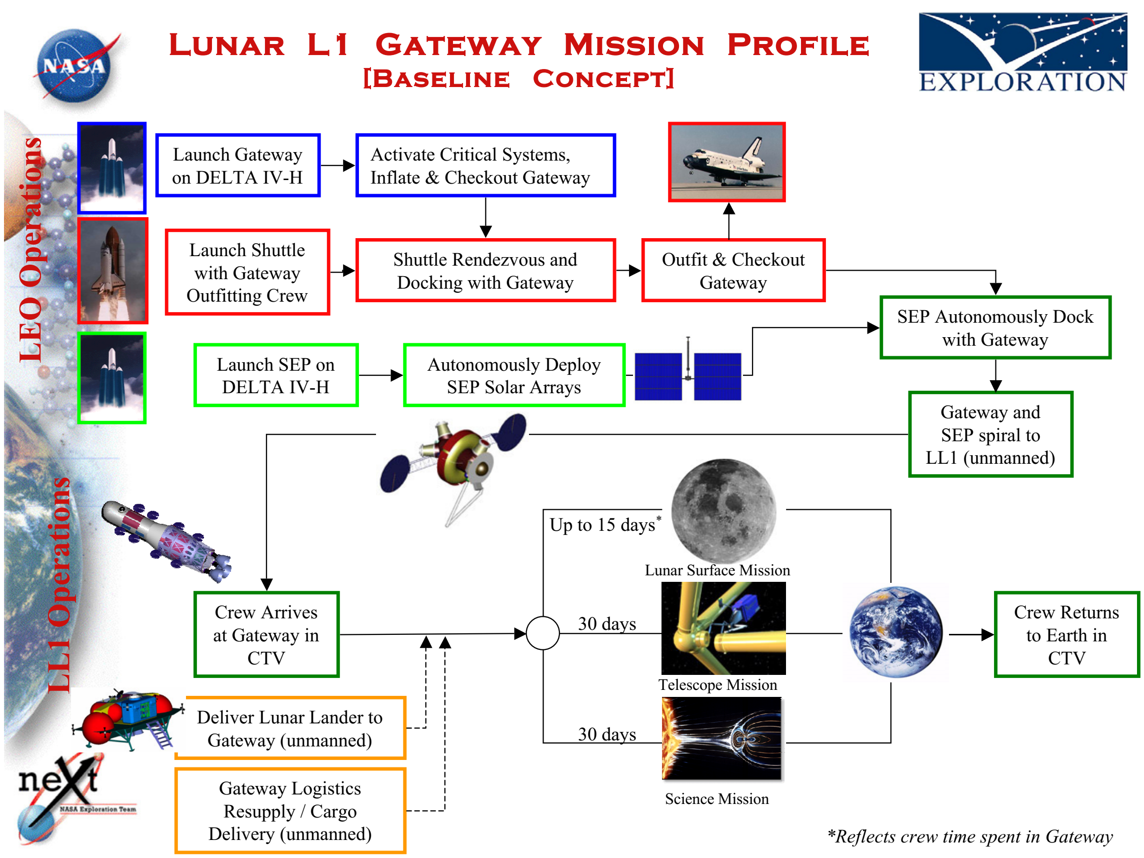
Lunar L1 Gateway Mission Profile
[Baseline Concept]
EXPLORATION
LEO Operations
LL1 Operations
Launch Gateway on DELTA IV-H
Activate Critical Systems, Inflate & Checkout Gateway
Launch Shuttle with Gateway Outfitting Crew
Shuttle Rendezvous and Docking with Gateway
Outfit & Checkout Gateway
SEP Autonomously Dock with Gateway
Launch SEP on DELTA IV-H
Autonomously Deploy SEP Solar Arrays
Gateway and SEP spiral to LL1 (unmanned)
Up to 15 days*
Lunar Surface Mission
30 days
Telescope Mission
30 days
Science Mission
Crew Arrives at Gateway in CTV
Crew Returns to Earth in CTV
Deliver Lunar Lander to Gateway (unmanned)
Gateway Logistics Resupply / Cargo Delivery (unmanned)
*Reflects crew time spent in Gateway
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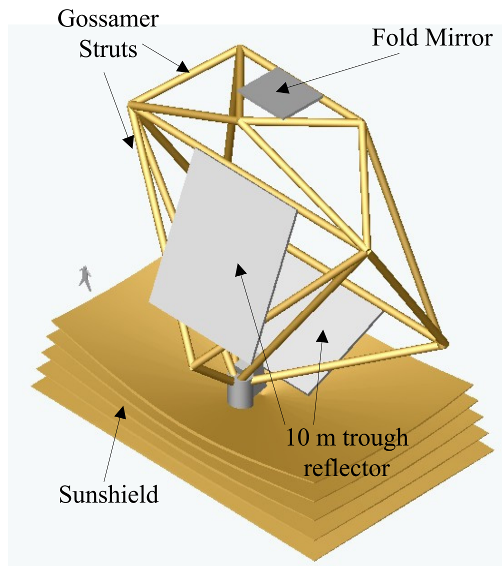
Far-IR Telescope Concept Construction
[Baseline Concept]

Hardware Support
- Docking for crew transfer vehicle and telescope component delivery module
- SSRMS-class large manipulator
- Small, dexterous robot to aid inspections and assembly/maintenance tasks
- EVA Airlock and teleoperator control station
- Unpressurized partially enclosed work area
- Structure/platform to restrain the telescope during work
- EVA and robotic-compatible storage areas for tools and telescope components

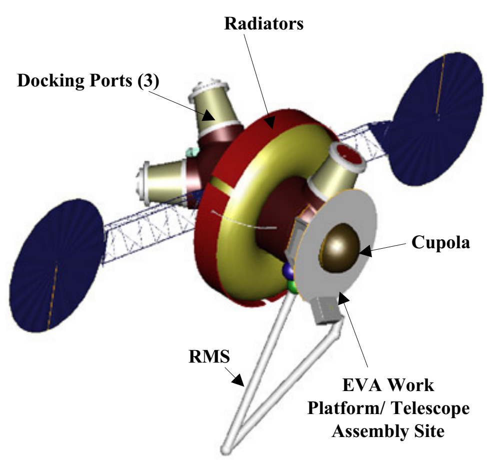
Mission Support
- Complete assembly at Lunar L1: **2 weeks** for **2 teams** of EVA crew; **6-8 EVA sorties**
- For telescope maintenance missions, assume **1 team** of EVA crew for **2 weeks**
- **Total Mission Time at Gateway: 25 days**

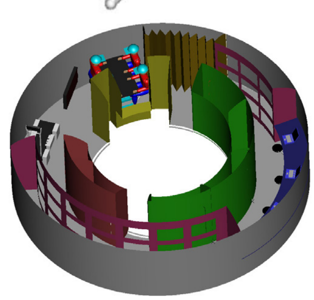


Gateway Concept Summary

- **Destination:** **Lunar L1**
- **Element Design Lifetime:** **15 yrs**
- **Crew Size:** **4 persons**
- **Mission Duration:** **10-30 days**
- **Element Mass:**
  - **Launch:** **22,827 kg**
  - **Outfitting:** **588 kg**
  - **Post-outfitting:** **23,415 kg**
- **Element Volume:**
  - **Launch:** **145 m^3**
  - **Inflated:** **275 m^3**

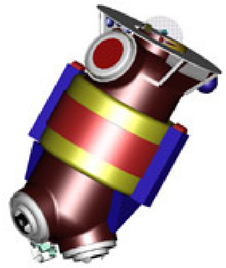
  (TransHab: ~340 m^3 for 7 persons)
- **Power provided:**
  - **Photovoltaic Array:** **12 kW Nominal**
  - **Energy Storage:** **Li-ion Batteries**
- **Support Missions:**
  - **Outfitting at LEO:** **One mission/architecture**
  - **Human Consumables:** **Two missions/year**
  - **Life Support resupply:** **One mission/two years**



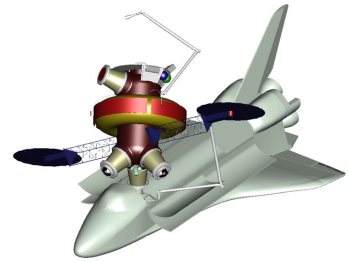


Gateway Configurations

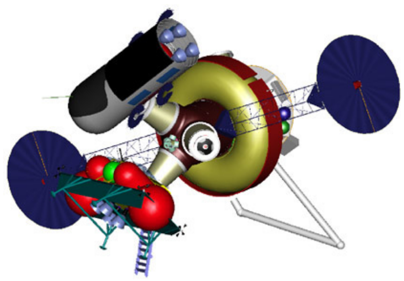
EXPLORATION



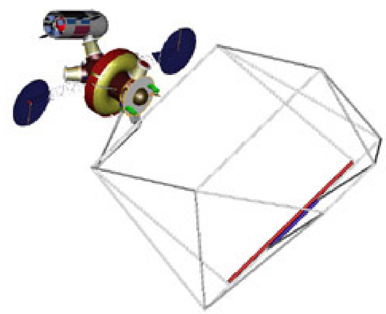
Launch Configuration



Gateway Outfitting in LEO



Lunar Surface Expedition

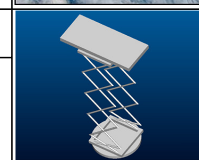


Telescope Assembly Mission

In-Depth Quantitative Analysis to Assess Human-Robot Optimization in Future Space Operations

- Relative strengths of humans and robots in performing a wide variety of tasks is well-established CONCEPTUALLY
  - Humans are unequaled in unstructured, unpredictable, innovative scenarios
  - Robots are best at high-risk access, many repetitive tasks
- There is much EXPERIENCE to validate these general notions
  - "Rescue" of HST and CGRO, Armstrong's lunar terminal descent maneuver, multiple examples on ISS
  - Robots have gone to "worse-than-hell" places (Venus, Jupiter) not currently accessible to humans
- Opinions and hunches about the value of humans/robots in space SIGNIFICANTLY EXCEED in-depth study and formal assessment
  - Need standardized METRICS to quantify performance
  - Need rigorously defined criteria to EVALUATE relative performance

Tools Available for Space Telescope Support

Humans		Robots	
1. EVA Astronaut Pairs of astronauts work in conjunction with robotic agents to assemble space telescopes. Two pairs of two EVA crew assumed on alternating EVAs.		1. Robonaut Dexterous anthropomorphic robot to complement human assembly agents. Provides fine motor skills, telerobotically controlled.	
2. RMS Operator RMS controlled from vehicle interior by IVA crewmember. Also controls RMS cameras and Mini-AERCam.		2. Remote Manipulator System (RMS) Shuttle/Gateway-based robotic arm for worksite support and payload manipulation	
3. Robonaut Operator Dexterous robot controlled via telepresence equipment. Operator may be IVA crewmember or Earth-based operator.		3. Assembly Table Notional concept for aiding telescope assembly. Robotic features may include worksite tilt, rotation, and elevation capabilities.	
4. Mission Control Provides mission support, guidance, and additional problem solving capability. May be used for telerobotic control in conjunction with IVA crewmember control.		4. Mini-AERCam Free-flying camera for close-proximity inspection. Controlled by IVA crewmember. Utilizes inert Xenon propulsion system to minimize contamination.	

Performance Case Study Process: Evaluating Options for Humans and/or Robots

Decompose Scenario: Facility Assembly

"Primitives" [aka, tasks]: Go to Site, Transport Load, Mate Objects . . .

Quantify Primitive Parameters

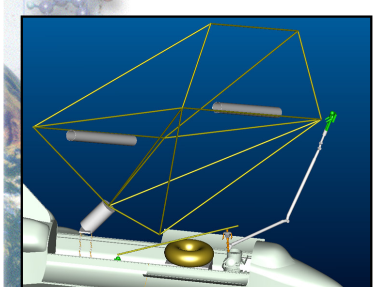
Parameters: EVA duration, transport distance, load mass & size, etc.

Determine "Aptitude"

Scores per primitive for each H/R system option: data base, thought experiments; models; etc.

Compute Composite Scores

Sum of all the task scores: e. g., probability of success for this H/R option



Example "Primitive" (task): 4.7-Agent moves to task site (Shuttle-based scenario)

Human-Robot (H/R) System Options Modeled:
- Astronauts-Only EVA
- Robot / Manipulator-Only EVA
- Astronauts Ride Transport Vehicle
- Robot-Assisted EVA
- Embedded Robotic Automation