On-orbit Assembly Possibilities for Large Telescopes

Where we are now

What's needed next

What the new capabilities could do

How might this come about

Rud Moe

GSFC

Brief Summary of Assembly History

Mission	On-orbit Assembly Accomplishments
Shuttle	
EASE ACCESS	Assembly of truss structure
HST Servicing	Retrofits to pre existing structures
ISS	Assembly of modules and structures

FLIGHT VALIDATION OF IN-SPACE ASSEMBLY CONCEPTS

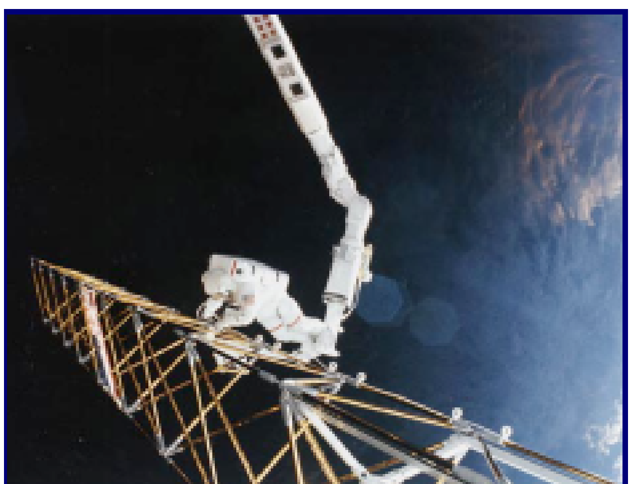
Baseline assembly of 10 bays

ACCESS

Assembly Concept for Construction in EVA of Space Structures

2 crew, assembly aids
17 sec/strut

- Demonstrated the ability to assemble a structure on orbit, perform maintenance, and install utilities.
- Demonstrated reliability of simulated 0-g



Utility line attachment simulation

Truss manipulation

Maintenance and Repair

HST Servicing

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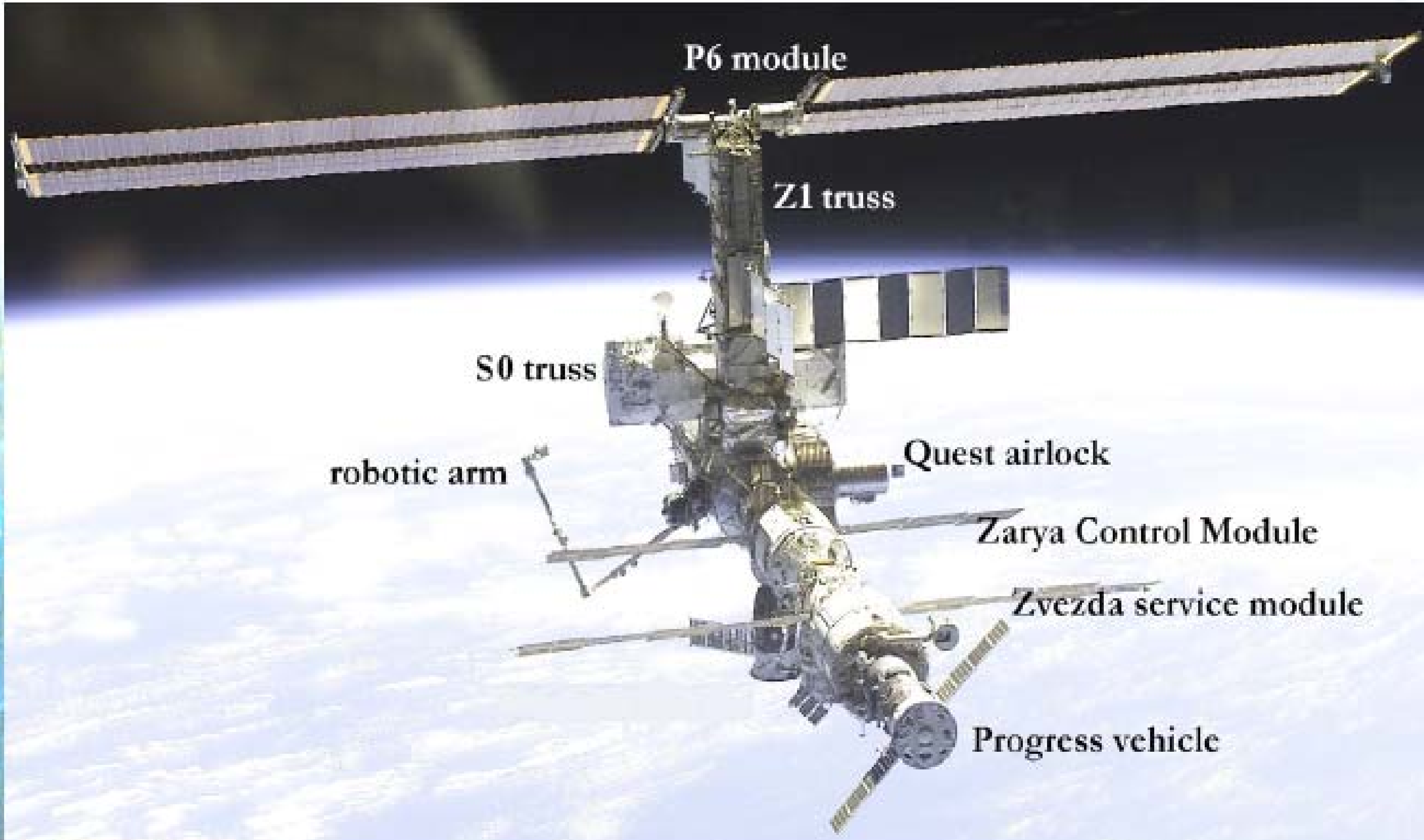
ISS assembly 4/2002



Development Path

Conceptual architectures in work

- Origins telescopes, SEC missions, ES missions
- NEXT Gateway, Advanced EVA, Assembly in space
- Commercial servicing, Remote robotics, GEO

Designs in work

- Design center cases (large telescope, Earth science facility)
- Upper stage accommodation: ?
- Refueling, modular servicing: Orbital Express

Test hardware in work

- Assembleable structures: LaRC, …
- Robots: several (JSC, UMD, CMU, JPL, LaRC, …)
- Auto-rendezvous: GSFC, MSFC, JSC, DARPA, …

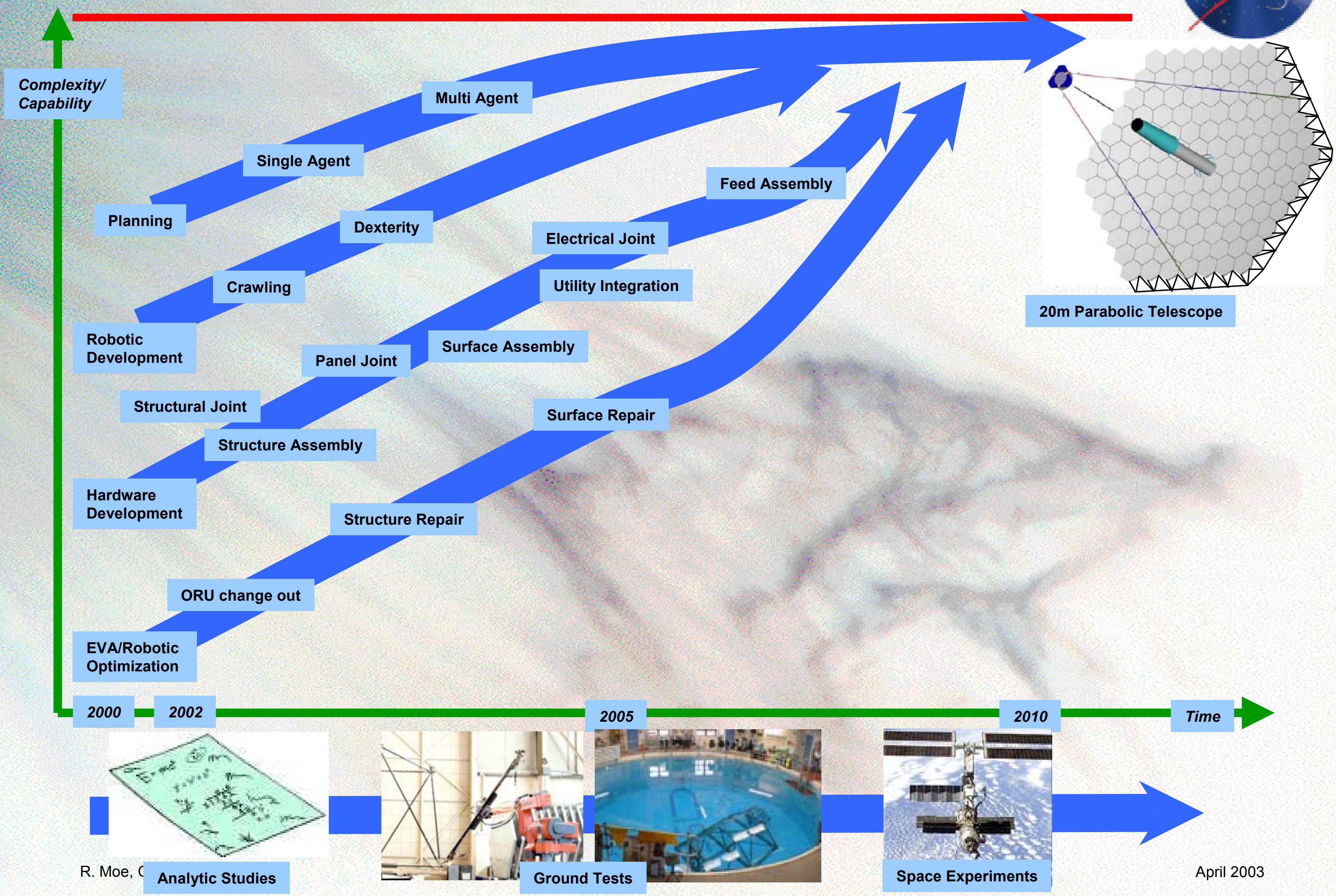
Assembly & servicing flight demonstration

- None in mission integration
- Use existing capability to support development

Current productive use of assembly & servicing capabilities

- HST, Shuttle, ISS, including carriers, tools, procedures
- Modular interfaces: several

Technology Development for Optimum Integration of Human and Robotic Roles



Access to Space, Productivity in Space

Robots beyond Shuttle, ISS, capabilities needed

- Shuttle or ELV launch availability
- Upper stage integration
- Auto-rendezvous and dock
- Communications
- Sustainability, resupply, self-maintenance
- Productive working capability

Human presence beyond Earth's magnetosphere, capabilities needed

- Habitable volumes
- Short transit, fast return
- Cosmic background radiation and Solar storms protection
- Zero-gravity mitigation
- Extended mission life support
- Logistical support, health and well-being
- Communications
- Productive working capability

Capabilities of Assembler/Servicer versus Accommodations Requirements on Facility

A wide range of facility approaches

- Simple or mission-optimized spacecraft—no special servicing accommodations
- Generic or modular spacecraft—some inherent system partition
- Minimally serviceable spacecraft—some rudimentary accommodations
- Designed for assembly & servicing—architectural features incorporated in design, build, test
- Integrated servicer-client system—mutually designed for interoperability, interdependence

A wide range of assembler/servicer capabilities, evolving over time

- EVA with safety provisions, airlocks, pressure suits, cranes, custom implements, power tools, interface accommodations, replacement hardware, carriers (current capability for Shuttle, ISS)
- IVA with telerobotics, cranes, custom implements, power tools, interface accommodations, replacement hardware, carriers (near capability for Shuttle, ISS)
- Remote telerobotics, with cranes, custom implements, power tools, interface accommodations, replacement hardware, carriers
- Advanced EVA with improved dexterity, sensing, control, requiring less accommodation
- Remote robotics, beyond teleoperation range, with improved dexterity, sensing, control, requiring less accommodation
- Advanced EVA synergistic with advanced telerobotic dexterity, sensing, control
- Autonomous remote robotics, beyond teleoperation range, with improved dexterity, sensing, control
- …

Allocation of Roles to Humans, Tools, Robots, Autonomy

Shared capabilities of humans and robots in space

- Presence, via space transportation
- Observation, usually via sensors
- Manipulation, usually via tools

Humans use tools at every level

- Implements for enhancing direct manipulation
- Motorized tools for enabling regimes of strength, speed, scale
- Electronics for enabling control, sensing, data

Direct handling is of limited use, mostly gross handling, translation

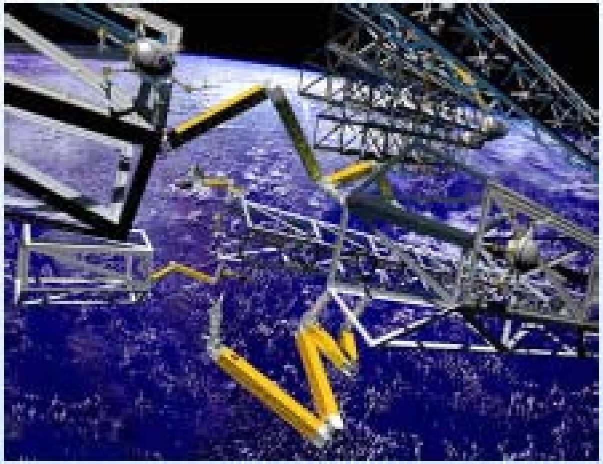
- EVA pressure suit reduces access, dexterity, sensing, control, imposes safety constraints
  - Suit enhancements for access, dexterity, sensing, control, greater inherent safety are required
- Robotic end effectors, grippers, torgers with cameras are also limited
- Dexterity, sensing, control can be achieved using advanced contols, tools, and sensors

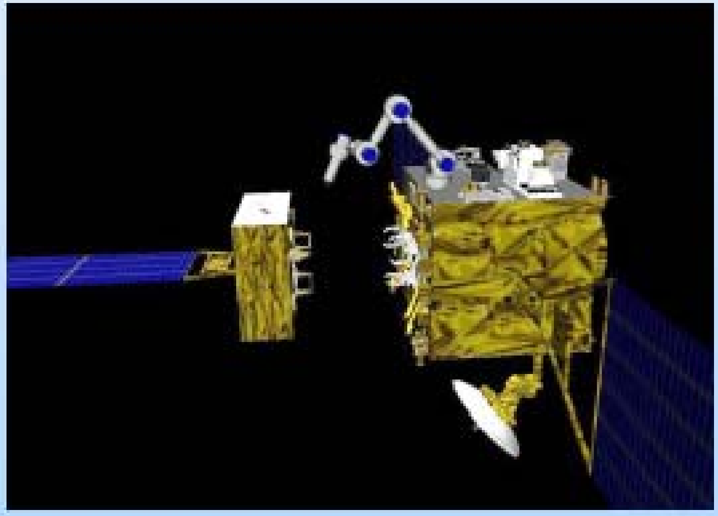
Telerobotics is currently used on Earth for microsurgery and remote surgery on humans, as well as earth moving and other heavy equipment operations, and exploration and operation in dangerous environments

- Intermediate step before autonomy

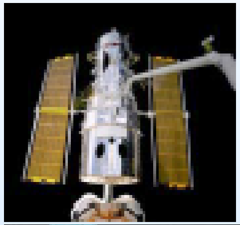
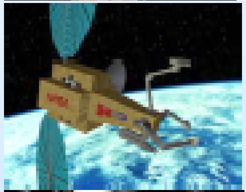
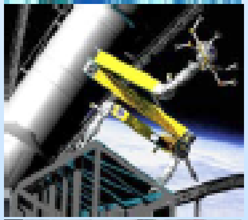
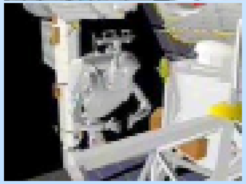
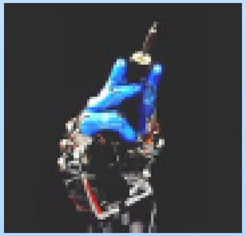
In-Space Robotic Assembly

- Solved (or will be soon):
  - Autonomous assembly of carefully designed mechanism in a static, known environment
  - Autonomous mating of robot-friendly connectors
- Challenges:
  - Autonomous assembly planning including responding to unforeseen situations
  - Recovering from errors/perturbations
  - Design and control of high DOF robot systems
  - Manipulation of fragile components





In-Space Assembly Overall Evaluation

- Teleoperated robots that move large components and mate parts
- Closely supervised, semi-autonomous robots that move large components and mate parts
- Teleoperated robots that can mate parts and make fine connections between parts
- Closely supervised, semi-autonomous robots that mate parts and make fine connections between parts
- Autonomous robots that move large components and mate parts with minimal human intervention
- Autonomous robots that mate parts and make fine connections between parts with minimal human intervention
- Autonomous robots that perform complete assembly of complicated structure (e.g., large telescope) from start to finish with substantial support from ground-based or in-space humans
- Autonomous robots that perform complete assembly of complicated structures (e.g., large telescope) from start to finish with minimal human intervention

Large, Complex Tasks Have Additional Requirements

Additional designs and test hardware needed for flight demonstration of complex assembly

- Local translation: cranes, structure climbing, clean propulsion
- Staging of components, tools, parts, materials
- Planning, inventory management, configuration control
- Positioning, fixturing, preassembly
- Protection for temporary configurations
- Contamination controls
- Soft goods handling
- Cryogenic environment, thermal control
- Figure control and final alignment, sensing and adjustments
- In-space integration and verification approaches
- Remote refueling
- …

Major OSS Mission Concepts Under Study for 2010+: Candidates for Human-Robotic Support

Science Missions currently under study for 2007 and beyond

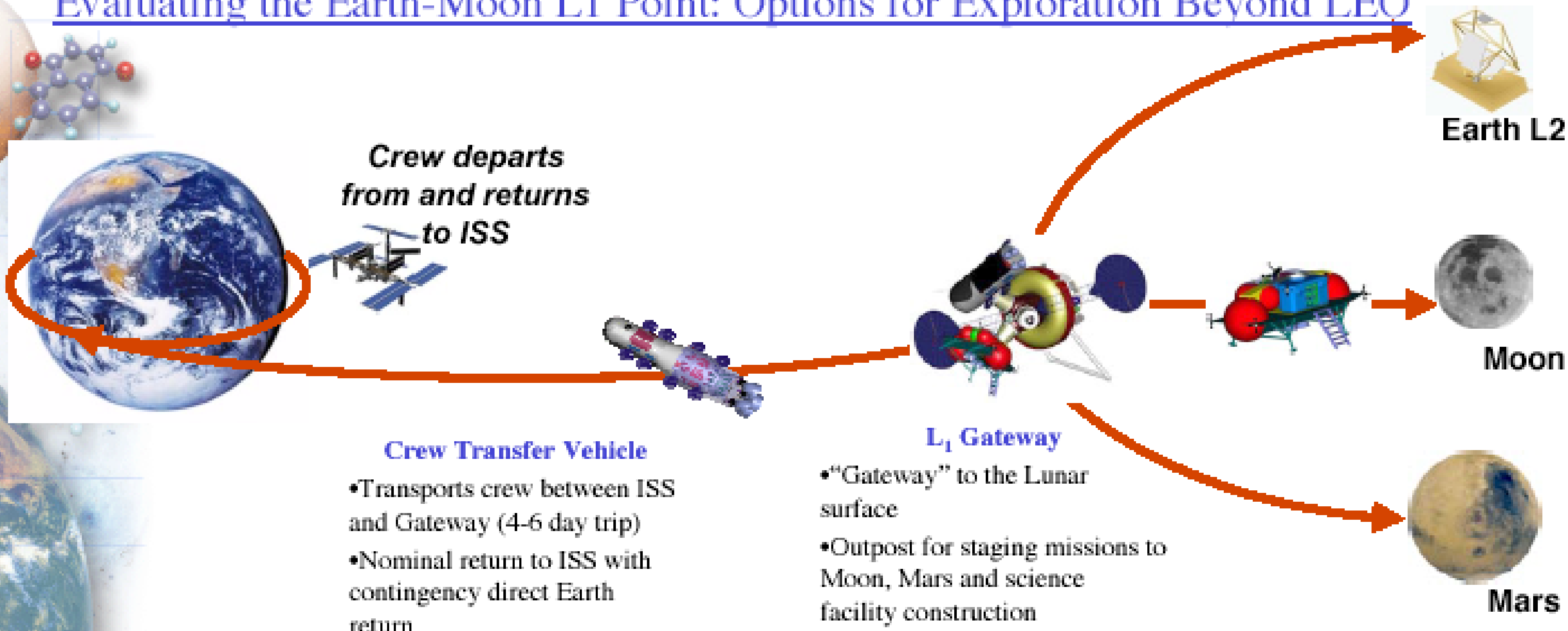
Mission	Description	Human Assembly	Human Servicing	Large Launch Vehicle	Fission Propulsion	RPS
ARISE	Advanced Radio Interferometry between Space and Earth	n	n	n		
CMBPOL	Cosmic Microwave Background Polarization	n	n	n		
Europa Subsurface	Penetration of frozen crust, and hunt for life below	n	n	y	probable	probabl
EXIST	Energetic X-ray Imaging Survey Telescope	n	n	n		
FAIR	Filled-Aperture Infrared Telescope	y, L1	y, L1	y		
HSI	High Resolution X-ray Spectroscopy Mission	y, LEO	n	n		
Interstellar Probe	solar wind termination shock & heliopause;significant penetration into the loca	y, L1	n, L1	y	probable	
ITM Wave Imaging	Ionosphere-Thermosphere-Mesosphere (ITM)	n	n	n		
Life Finder	Detecting spectroscopic signs of life on nearby extrasolar planets.	y	y	y		
MAXIM Pathfinder	MicroArcsecond X-ray Imaging Mission Pathfinder	(y)	(y)	y		
Microscale Coronal Features	imaging and spectroscopic data able to resolve microscale coronal features.	n	n	n		
Neptune Orbiter	Neptune & Triton	n	n	y	probable	probable
OWL	Orbiting Wide-angle Light-collectors	n	n	n		
Planet Imager	An array of interferometers that each carried NGST-sized telescopes (about e	y	y	y		
Saturn Ring Observer	detailed investigations of complex dynamic processes in rings	n	n	y	possible	probable
Solar Polar Imager	data from above Sun's poles to complement data fromecliptic plane.	y*, LEO	n	y		
SPIRIT	Space Infrared Interferometric Telescope	y**, L1	n	y		
SUVO	Space Ultraviolet Optical Telescope	y, L1	y, L1	y		
Venus SSR	Venus Surface Sample Return	n	n	y		probabl

* May use solar sail; potential human deployment of sail

**Possible human deployment of interferometer

Gateway Architecture

Evaluating the Earth-Moon L1 Point: Options for Exploration Beyond LEO



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

Investment Stategy

Cost reduction of development of transportation, human, and robotic capabilities

Investment costs spread across all users and beneficiaries

- Generic capability captures more users than does specific or narrow requirements
- Commonality features capture even more investors

Experience and capital accumulation through continuity build value

- Reusability and extensibility features capture even more investors

Inadequate investment is the enemy of adequate investment

- Users must interact with supporting capabilty design requirements

Agency Goals are Basis for Integration

The Integrated Space Plan integrates across Enterprises/Themes by focusing on the 10 Agency goals:

		Science, Aeronautics & Exploration												*Space Flight Capabilities*					
		SSE					ESE		OBPR			R	N	OSF			OAT		
	Themes	Solar System exploration	Mars Exploration Program	Astronomical search for Origin	Structure & Evol'n of the Univ	Sun-Earth Connections	Earth System Science	Earth Science Applications	Biological Sciences Res/	Physical Sciences Res.	Research Partnerships[s	Aeronautics Technology	Education Program	International Space Station (IS	Space Shuttle Program (SSP)	Space & Flight Support	Space Launch Initiative (SLI)	Mission & Science Meas. Tec	Innovative T*T Partnerships
Protect	1. Understand Earth's system…	●				●	●	●						○	○	○			
Protect	2. Enable…safer… air transportation											●							
Protect	3. Create a more secure world…quality of life									●	●	●		○		○	●		●
Explore	4. Explore the fundamental principles…								●	●				○	○				
Explore	5. Explore solar system & universe beyond	●	●	●	●	●									○	○			
Inspire	6. Inspire & motivate students	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○
Inspire	7. Engage the public	○	○	○	○	○	○	○	○	○	○	○	●	○	○	○	○	○	○
Enabling	8. Ensure… space access													●	●	●	●		
Enabling	9. Extend the duration & boundaries of human…		○						●	●				●	○	●	○	○	
Enabling	10. Enabler revolutionary capabilities…technology											●				●		●	●

● Primary contributor toward achieving Goal, accountable for at least one Objective.

○ Supporting contributor toward achieving Objective, accountable for at least one Performance Measure.

The Integrated Space Plan shapes the future direction in space for NASA strategic planning

Space Architecture Planning Process