



NASA Exploration Team Report



*Charting America's Course
for Exploration & Discovery
in the
Twenty-first Century*





Exploration & Discovery in the National Interest



- NASA must have a unified vision and strategy to prepare for the future and make wise investments, while addressing current problems
 - The Exploration of space- discovery driven, technology enabled; to develop capabilities and scientific knowledge for the best possible return for America
- Agency-wide “NASA Exploration Team” – OMB chartered to identify innovative approaches and unique technologies, enabling efficient and affordable exploration of space
- Significant progress has been made towards this goal
- Through new management processes, NASA can be integrated, its programs focused, and investments carefully made to pursue a unified vision
 - Adopt a stepping stone approach to capability development and Space Exploration within and beyond Earth orbit
 - Focus existing technology programs
 - Invest in identified technology gaps
 - Leverage as well as contribute to existing programs through development and demonstration of new capabilities
 - Prevent problems of the past through proper preparation
 - Provide for the broadest possible public engagement and dissemination of knowledge



NASA Exploration Team



- Chartered to create an environment for discovery by integrating Agency plans into a unified vision and strategy for space exploration
 - Identify and advocate supporting technology investments
 - Cut across bureaucratic stovepipes
 - Investigate revolutionary approaches
 - Use a systems engineering approach
 - An embargoed process reporting to senior management
- Accomplishments:
 - Established agency-wide team (Virtual Think Tank)
 - Developed a vision, new strategies, and new mission concepts for future human and robotic exploration
 - Developed detailed technology gaps, roadmaps, and priorities to enable science-driven exploration
 - Progress in collaboration with Mars Program, Space Launch Initiative
 - Identification of synergies in technology needs among Enterprises
 - Succeeded with initiatives in:
 - In Space Transportation
 - Technology and Commercialization Initiative (later cancelled in ISS budget scrub)



Virtual Think Tank for Space Exploration

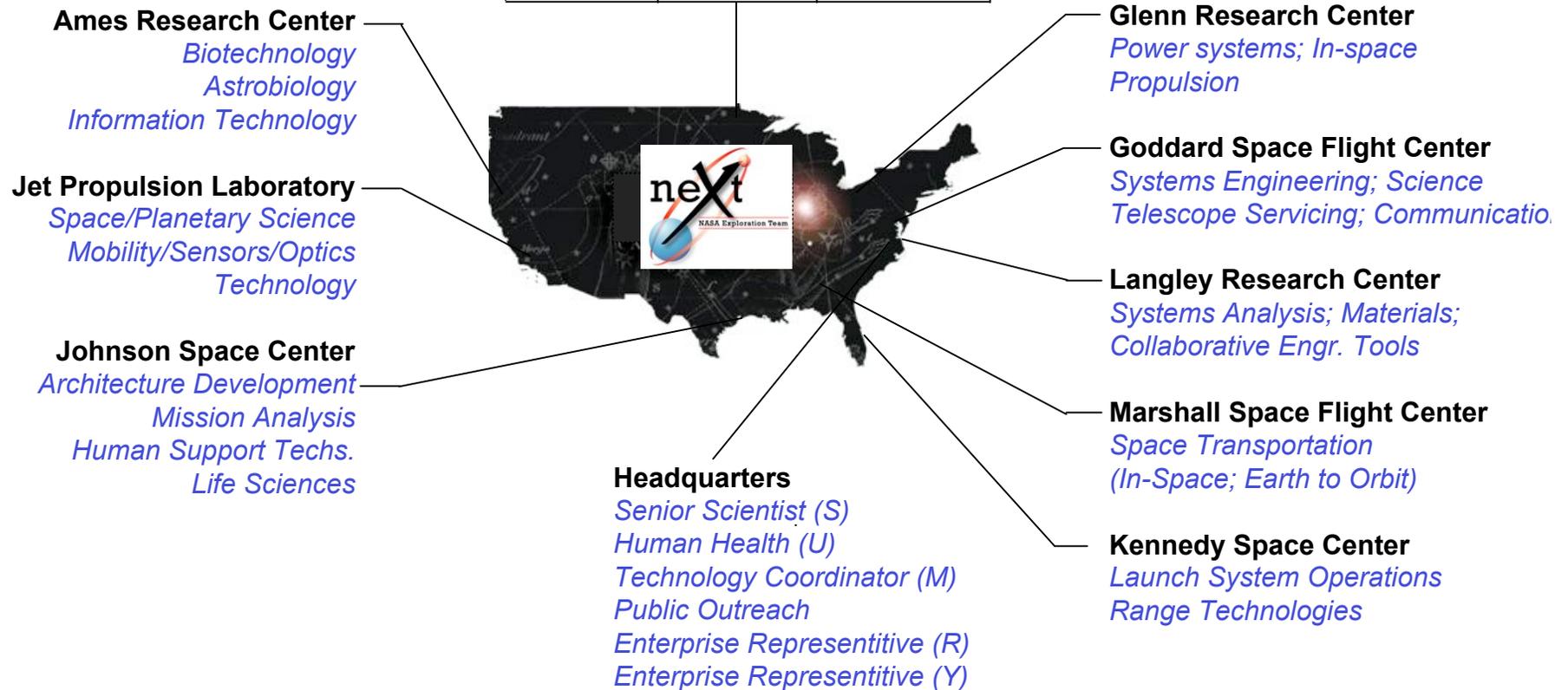


- Team is agency-wide, lead by Gary Martin at HQ

Enterprise Sponsors:

J. Rothenberg/OSF

E. Weiler/OSS





Strategy



Driven by science and discovery for the National Interest



Optimized use of humans and robots to increase the pace of discovery at multiple destinations.

Unifying Agency vision



Integrated Enterprise and center strategies

Safety and cost conscious



Technology priorities and mission concepts to enhance reliability, flexibility, capability, and affordability

Progressive approach



“Stepping stone” technology investments and mission opportunities

Leveraging partnerships



International, governmental, academic and industrial partners.

Emphasizing education



Inspiring and educating future generations.



NATIONAL AERONAUTICS AND SPACE ACT OF 1958, AS AMENDED



Primary Tenets:

- Activities in space- devoted to peaceful purposes for the benefit of all mankind
- General welfare and security of the United States require ... aeronautical and space activities
- Seek and encourage to the maximum extent possible the fullest commercial use of space



NATIONAL AERONAUTICS AND SPACE ACT OF 1958, AS AMENDED



Primary Objectives:

Contribute materially to one or more of the following objectives:

- Expansion of human knowledge of the Earth and of phenomena in the atmosphere and space
- Improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles
- Development and operation of vehicles capable of carrying instruments, equipment, supplies, and living organisms through space
- Establishment of long-range studies of the potential benefits to be gained from the utilization of aeronautical and space activities
- Preservation of the role of the United States as a leader in aeronautical and space science and technology
- Sharing discoveries between NASA and national defense agencies
- Cooperation by the United States with other nations
- Effective utilization of the scientific and engineering resources, avoiding unnecessary duplication of effort with other agencies



NATIONAL AERONAUTICS AND SPACE ACT OF 1958, AS AMENDED



Primary Objectives (Cont.)

Competence in scientific and engineering systems be directed toward ground propulsion systems research and development

- Competence in scientific and engineering systems be directed toward advanced automobile propulsion systems
- Competence in scientific and engineering systems be directed toward assisting in bioengineering research, development, and demonstration programs designed to alleviate and minimize the effects of disability



Exploration & Discovery in the National Interest



NExT strategy designed to maximize return to U.S. Citizens based on National Interests, the NASA Strategic Plan, and its Goals & Objectives ¹

National Security ²

- Make available to agencies concerned with national defense discoveries and technologies of military value ²
- Provide unique R&T and scientific facilities ²
- Cooperation with other Nations ²

Provide for the General Welfare ²

- Expand and disseminate scientific knowledge and understanding ²
- Preserve U.S. preeminence position in space R&T development ²
- NASA bioengineering in support of the General Welfare and health of the U.S. Citizen ²
- Inspire the next generation of students in math and science excellence ¹

Full Commercial Use ²

- Develop pre-competitive technologies with significant commercial application ²
- Open the way for U.S. citizens by Privatization and commercialization of the space environment ¹
- Foster an educated workforce ¹
- Promote global economic growth

1. NASA Strategic Plan 2000 - 2003

2. The National Aeronautics and Space Act



NASA Strategic Plan



- NASA is an investment in America's future. As explorers, pioneers and innovators, we boldly expand frontiers in air and space to inspire and serve America to benefit the quality of life on Earth
- NASA' Mission
 - To advance and communicate scientific knowledge and understanding of the Earth, the solar system, and the universe
 - To advance human exploration, use and development of space
 - To research, develop, verify, and transfer advanced aeronautics and space technologies



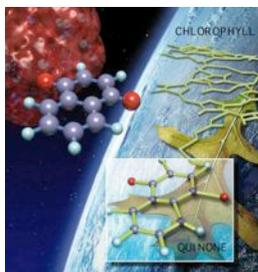
Exploration Grand Challenges



To *discover* scientific evidence and processes that *reveal* our place in the Universe, by:

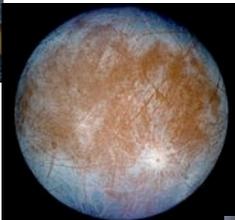
- *exploring* new places and phenomena,
- *leading* outward beyond the vicinity of the Earth,
- *enhancing* the quality of life and
- *sharing* the adventure of discovery with all humanity.

The imperative for space exploration can be articulated by *Grand Challenges* such as these:



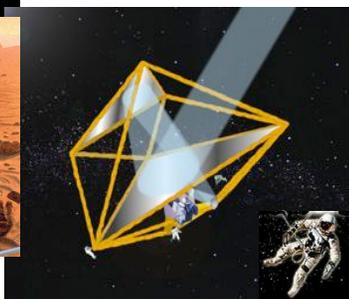
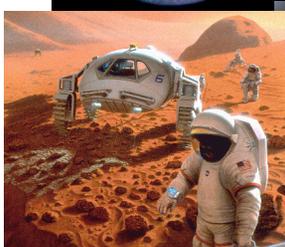
How did we get here?

- How did the universe form and evolve?
- What are the origins of life in the universe?



Are we alone?

- Is there evidence of life, past or present, elsewhere in the solar system or Universe?



Where are we going?

- What is the future of our planet, its climate and inhabitants?
- What is the future of space exploration and development?



Exploration Strategies

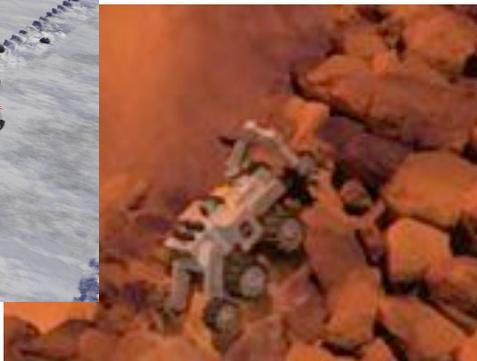


Revolutionize the suite of technologies and capabilities that enable discovery and science return, lead to commercialization of space and provide the maximum return to the nation:

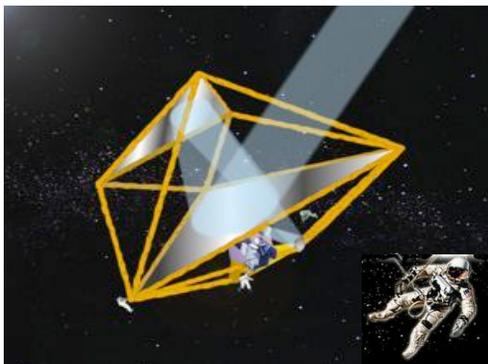
- Remote observations and measurements- reach as far into the universe as possible; understand the Earth and its processes
 - Further the incredible discoveries of Hubble Space Telescope to understand our universe, its, evolution and processes
 - Search for evidence of life on planets outside our solar system
 - Develop a scientific understanding of the Earth system and its responses
- Robotic missions- maximize the return from remote direct measurements of other planetary bodies
 - Further automation and virtual presence to increase the return of in-situ measurements
 - Measure the environments and test technologies preparing for follow-on missions and objectives
- Human exploration- enable cost effective human exploration,
 - Where human capabilities can enable and increase the rate of return of science and discovery
 - Share the excitement of first hand discoveries through virtual presence
 - Develop an infrastructure that enables commercial access to space and the planets



Discovery: Cosmic Origins and Destiny



Search for life, Climate and Geophysical sciences at other planets; Implications for Earth



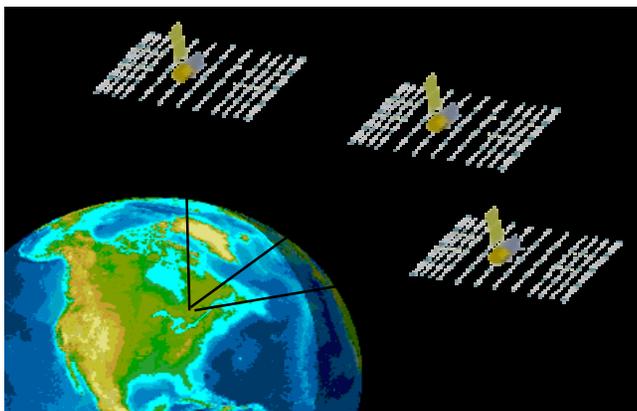
The birth of stars and planets

Searching for biomarkers in planetary atmospheres

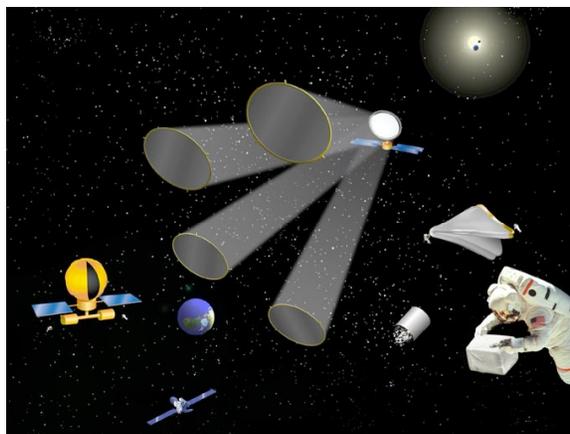


Lunar impact and solar wind history: context for history of the solar system

Detailed environmental monitoring



Studying habitability around neighboring stars





Why Mars?



- Mars is the planet most like our own
 - Evolving climate processes
 - Polar caps
 - Evidence of past and present existence of water
 - Equivalent land surface areas
 - Interesting features
- Compelling questions:
 - Is there, or has there been, life on Mars?
 - Why have there been dramatic climate changes?
 - What can Mars tell us about the future of Earth?
 - What resources can Mars contribute to mission sustainability or have value at Earth?



Why the Moon?



- Earth's nearest neighbor
- The moon is a record of 4 billion years of history, relevant to Earth and solar system history
 - Impact history
 - Solar wind
- Potential test bed for human missions to Mars
 - Risk reduction
 - Planetary experience in operation near Earth
- Infrastructure can enable commercial opportunities
 - Resources?
 - He₃
 - Regolith resources
 - Water/Ice
 - Tourism?





Humans and Robots



- Humans and robots/machines collaborate in every mission
 - Differences characterized by the interface and proximity
 - The proper mix of humans and machines should be determined to achieve objectives
- *Robotic Missions*- Robots and machines augment capabilities of humans and extend their reach into the solar system and beyond
 - Remote observations and measurements
 - Interaction with the environment
 - Robots can operate in environments too hazardous for humans
 - Demonstration and implementation of technologies
 - Robotic missions are smaller bite-sized missions with smaller funding commitments
 - Because they are smaller scale missions, science and its rate of return is limited. May take decades to obtain desired objectives (Mars)



Humans and Robots

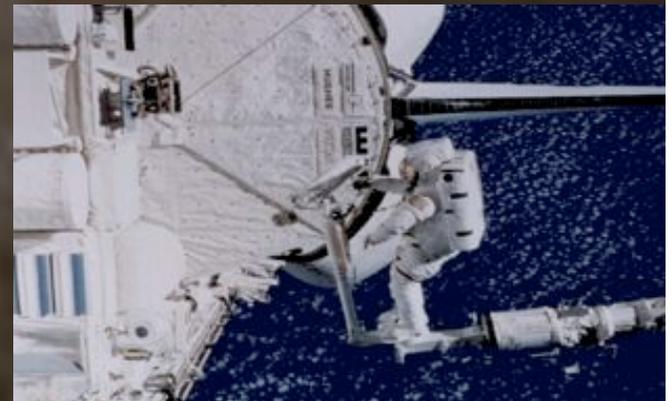
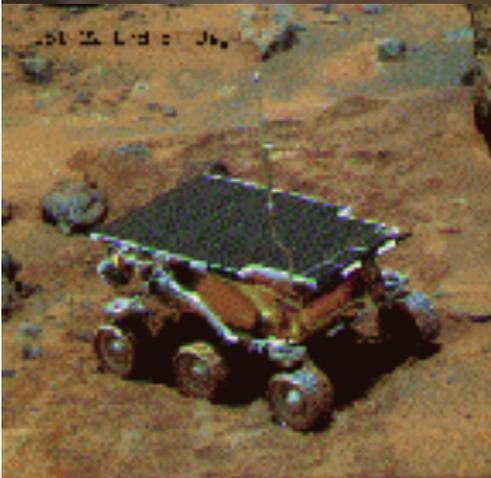
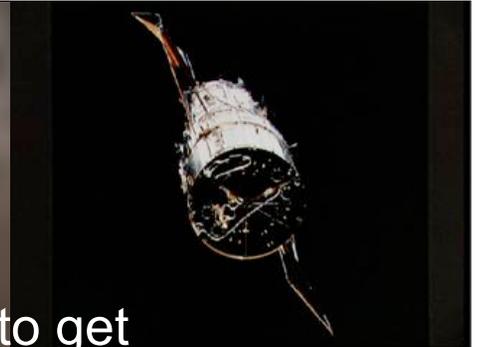


- For both human and robotic missions, more autonomy in machines/robots are needed to reduce the necessary degree of human interaction
 - Computer-machine intelligence and problem solving
 - More complete and accessible onboard information
 - Reduce ground support, saving money
- *Human Missions*- Communicate, first hand, the excitement of discovery
 - Scale of missions inherently larger/ more costly
 - More complete range of observations/measurements possible on a mission
 - In-situ investigations and human interaction closer to what is possible in the laboratory
 - Ability to intercede in hardware/software problems and failures
 - Human mind reacts to inputs instantaneously, drawing on experience of a lifetime
 - Greater flexibility to react to the totally unexpected and changing objectives
 - Hubble Space Telescope and Apollo demonstrated significant increase in rate of science return through direct interaction of humans in-situ

Humans and Robots

For the future:

- How do we apply the best state of technology to get the most from our machine, robot, computational, and human capabilities?
- How do we develop the most effective interfaces between people and machines?
- Ultimately, how do we augment/ integrate human performance with advanced machines to maximize overall mission performance, flexibility, and achievement?





Exploration & Discovery in the National Interest



- Accurately predict complexity and cost by fully understanding technical challenges, international and commercial partnering through;
- New technologies and innovative mission approaches
 - Low-cost Earth analogs
 - International Space Station research and testing
 - Leveraging of other programs
 - Test and demonstrate technologies
 - Investigate environmental factors to benefit future missions
 - Stepping stone approach for future exploration
 - Address new “best practices” management techniques needed to manage large complex missions



Example: Earth Analogs



- Cost and schedule of planetary missions can be accurately predicted by “flying a mission” in terrestrial analogs before funding is committed for the actual flight.
- Design, build, and test missions in a relatively low-cost analog to fully understand technical challenges, international and commercial partnering required for complex missions



Planetary Simulation

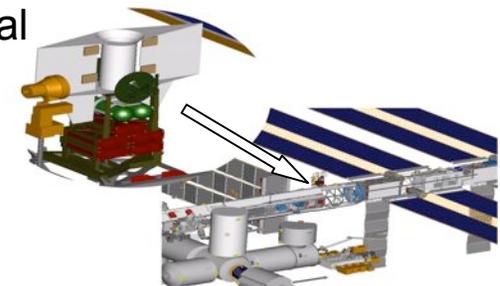


Demonstration of Technologies at ISS



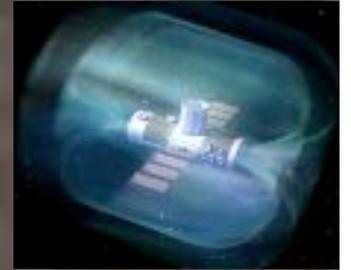
Research at ISS can benefit ISS as well as future programs:

- Improve performance and crew productivity
 - Automation of systems, payloads, health monitoring, intelligent agent technologies
 - Advanced crew interfaces enhance crew effectiveness
- Reduce resupply and logistics
 - Plasma engines can perform reboost with existing waste H₂
 - Closed loop life support minimizes consumables use
 - MEMS/wireless technologies provide functions with reduced drain or impact on ISS resources or infrastructure.
 - Miniature sensors, processors, and other devices have minimal impact on sparing.
- Improve knowledge base on space environmental effects on humans contributes to better health and safety for crews,
 - Zero G
 - Radiation
 - Human performance over long mission durations
- Systems exposure to operational and space environment
 - Contributes to long term reliability
 - Contributes to evolution of simpler designs and better control of functions

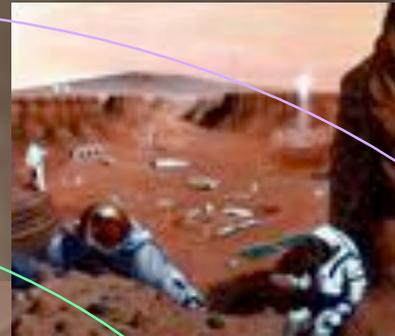


Stepping Stones

Go anywhere, anytime



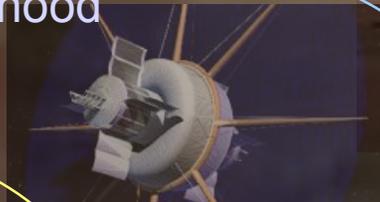
Sustainable Planetary Surfaces



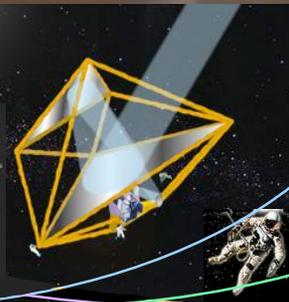
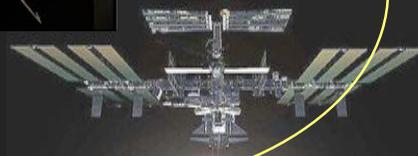
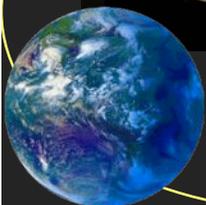
Accessible Planetary Surface



Earth's Neighborhood



Earth and LEO





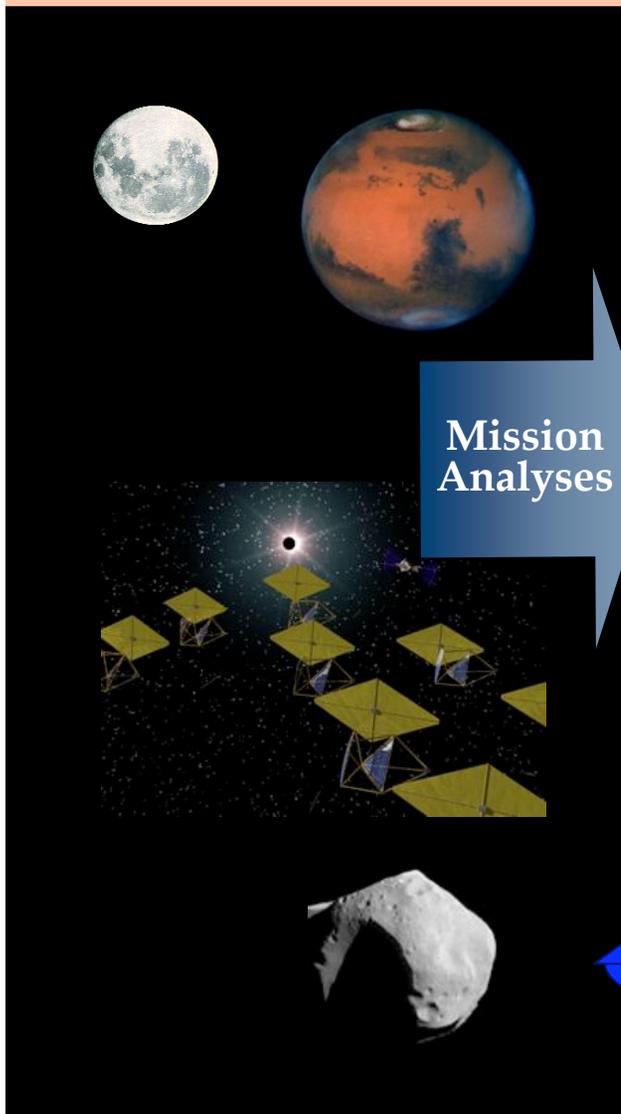
Core Capabilities & Technologies



Potential Destinations from Science Objectives

Common Capabilities

Technology Building Blocks



Mission Analyses



System Design(s)

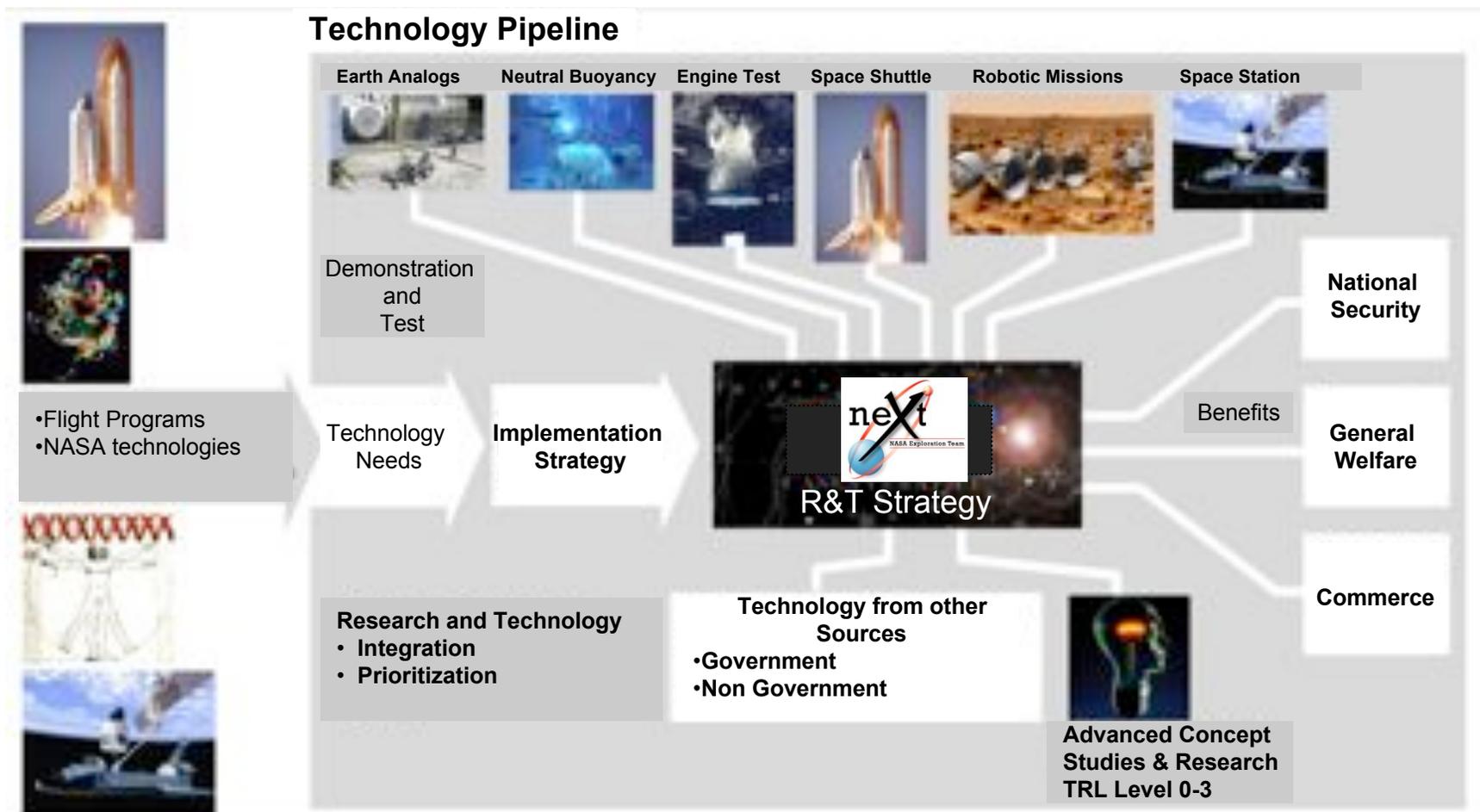
- "Breakthrough" Technologies (Examples)*
- Efficient In-Space
 - Aeroassist
 - Low-cost Engines
 - Cryo Fluid
 - Robust/Efficient
 - Lightweight
 - Radiation Research
 - Zero/Low-g Research
 - Regenerable Life
 - Advanced Lightweight EVA
 - Wireless Power Transmission
 - Regenerative
 - Revolutionary ETO Rockets
 - Innovative Mission Concepts



NExT Research and Technology Strategy



- The NExT technology strategy is to focus technology investments to maximize mission performance and serve the National Interest

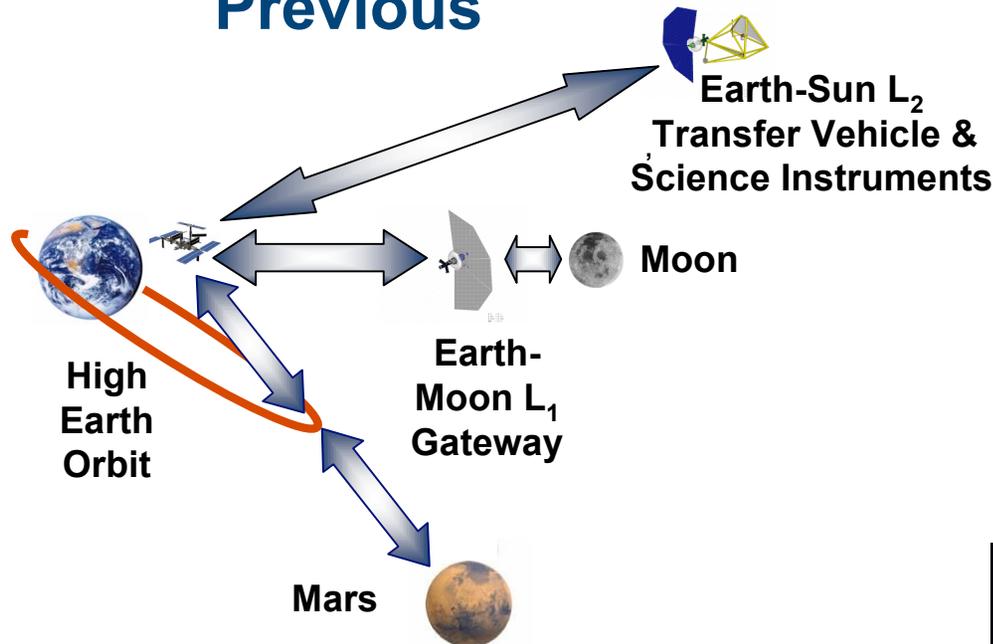




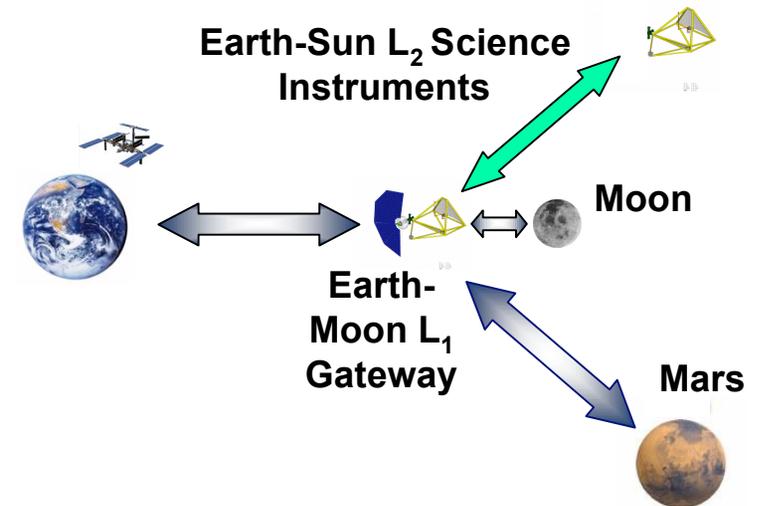
Simplifying Earth's Neighborhood Infrastructure



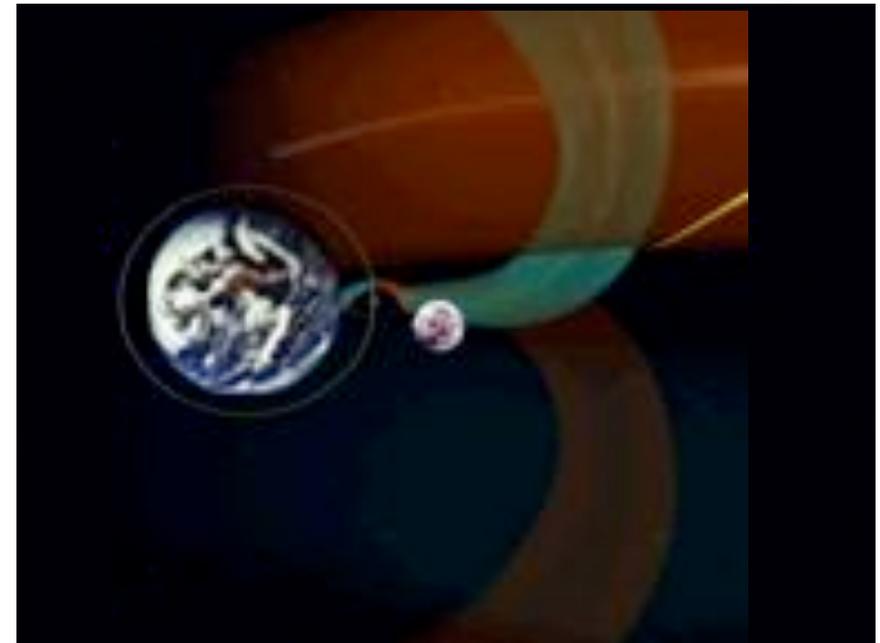
Previous



Simplified



- **Space Super Highways** are corridors through the Solar System that balance the gravitational forces of the Sun and the Planets.
- Vehicles require minimal thrust and mass to move from one Libration point to another Libration Point
- Earth System to Mars System transfers have the potential to transfer cargo at significant cost reduction over previous trajectory designs



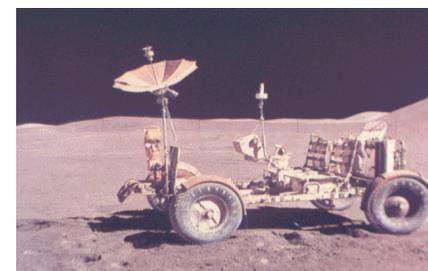
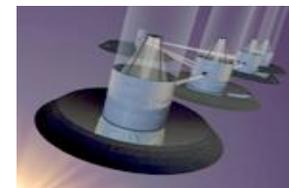
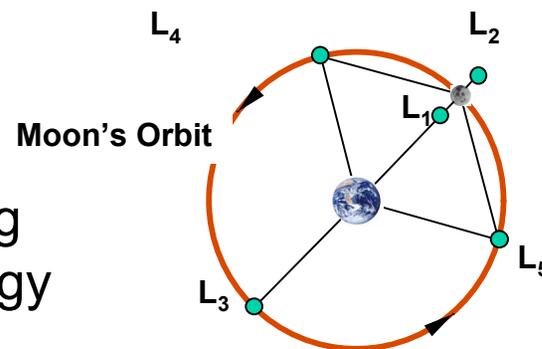


“Earth Neighborhood Gateway”



Key Attributes

- Earth-Sun Telescope assembly and servicing
- Gateway serves as “stepping stone” by providing an opportunity to test and demonstrate technology and operational concepts
- Architecture can be bought “by the yard” resulting in increasing capabilities and operational experience
- Employs existing and modest augmentation of existing commercial launch vehicles
- Common architecture elements for all Earth’s Neighborhood missions
- Possible benefits in repairing outbound planetary spacecraft
- Possible value for storing military assets





A New Approach Mars Lagrange Point Staging Location



- Invariant Manifold transfers
 - Low energy transfers between Earth-moon L_1 and Mars L_{1-2}
- Move Mars tele-operation from Earth to Mars L_1
 - Deploy and operate micro-missions
 - Short light time (3.6 sec.)
- Reduce mass and cost
 - Stay out of Mars gravity well -aerocapture for transit vehicle not needed
 - Mars Gateway and Earth-moon Gateway are same design
 - Enables reuse of transit vehicles
- Fuel depots at Moon and Mars gateways:
 - Potential fuel sources: Earth, Moon, Mars
- Safe locations to operate nuclear electric propulsion if needed
- Equivalent access to all of Mars surface
- More versatile departure times vs. 500 or 1000 day mission scenarios??
- Use existing or planned launch vehicles??
- Stepping stone for humans to Mars with incremental investments



Enabling the Stepping Stones



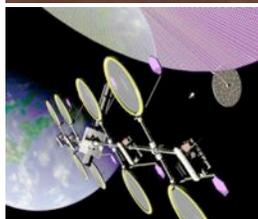
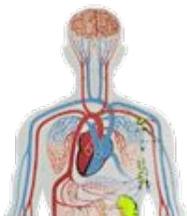
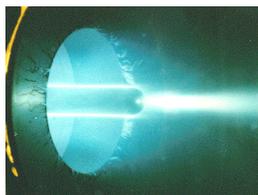
The Hurdles

- **In-Space Transportation**
 - Safe, highly efficient, and economical
 - Multi-use, robotic and human applications
- **Crew Health and Safety**
 - Countermeasures to environmental effects
 - Medical autonomy
- **Human/Robotic Partnership**
 - Dramatically higher productivity,
 - On-site intelligence
- **Affordable, Abundant Power**
 - Solar
 - Nuclear
- **Space Systems Performance**
 - Low-mass, highly automated
 - Automated reasoning, smart sensing, reliability

What must we know to make informed decisions?

The Criteria

- **Sufficient knowledge about destinations to reduce uncertainty**
- **Certification of systems and/or crews for deep space operations**
- **Acceptable technology readiness achieved**
- **Affordable and efficient mission concepts**
- **High return anticipated**
 - Science impact
 - Education Benefits
 - Valued technology for the nation
- **Goals/objectives defined for optimal mix of robots and humans**
- **Partnership opportunities identified**





Proposed Approach for NASA's Future



To prepare for the future, NASA must be integrated, its programs focused, and investments carefully made to pursue a **unified vision** and contribute to National Interests; while addressing current problems

- The Exploration of space- discovery driven, technology enabled; to develop capabilities and scientific knowledge for the best possible return for America
- Adopt a stepping stone approach to capability development and Space Exploration within and beyond earth orbit
- Develop management processes to assure alignment and focus on NASA's vision and goals
- Focus existing technology programs to address vision and National needs
- Invest in identified technology gaps
- Leverage as well as contribute to existing programs through development, testing and demonstration of new technologies/capabilities
 - Better understand costs for next steps in Exploration
 - Enhance performance and return from current programs
- Prevent problems of the past through proper preparation
- Provide for the broadest possible public engagement and dissemination of knowledge



A Future In Space



21st Century

➔ A pivotal time to set the course for America's future in space, starting with this decade.

First Decade

➔ A critical decade for discoveries, innovations, opportunities and decisions

Today

➔ A unified, visionary plan to explore and develop space effectively for the benefit of the nation

"As for the future, your task is not to foresee it, but to enable it."

A. de Saint-Exupery



Architecture/ Technology Investment Successes



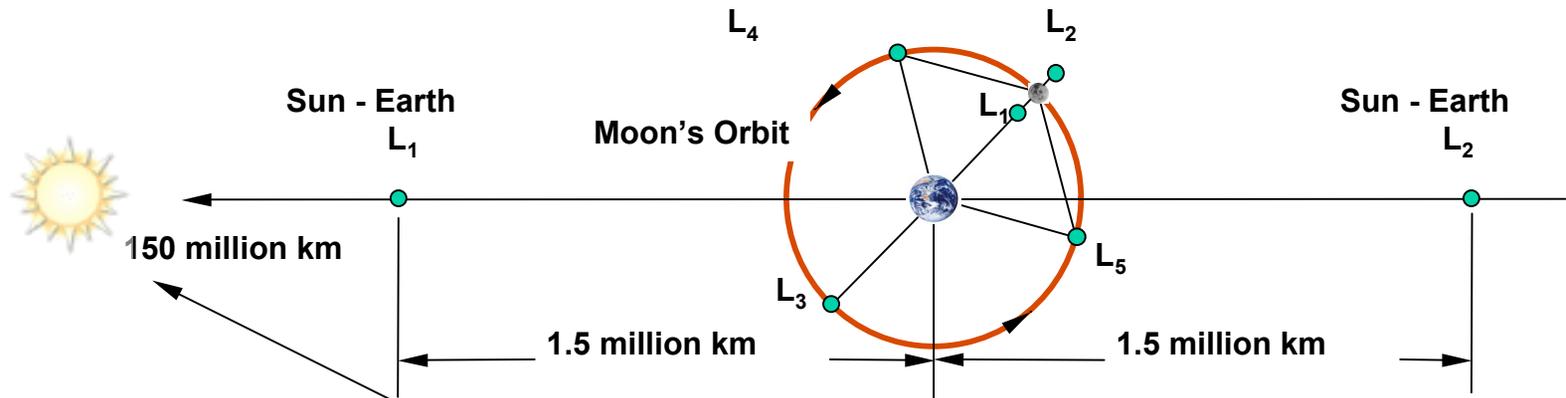
- In-space Transportation
- Nuclear power and propulsion
- Radiation mitigation
- Low energy trajectories
- Lagrange point gateways
- Gossamer telescopes
- Value to ISS
- THREADS gap analysis, requirements, roadmaps and priorities
- Leverage internal and external opportunities and programs



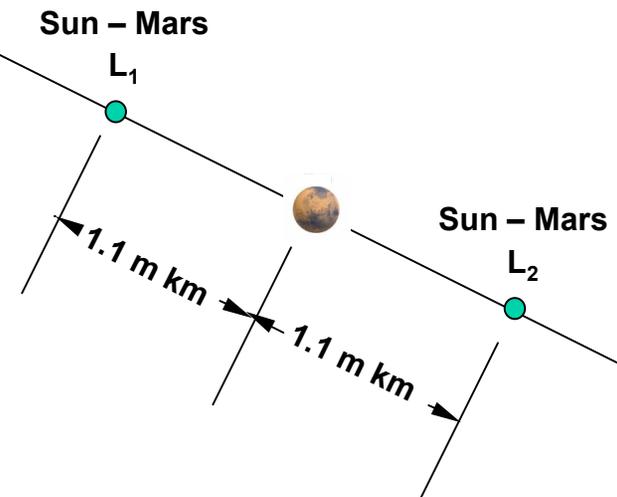
Backup



A new Approach Earth and Mars Neighborhoods

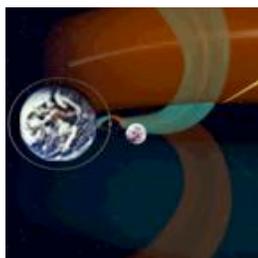


- Libration Points are relatively stable locations in space oriented to orbiting planetary bodies
- Access to all locations on moon and Mars is equivalent
- Very low energy transfers between libration points are possible

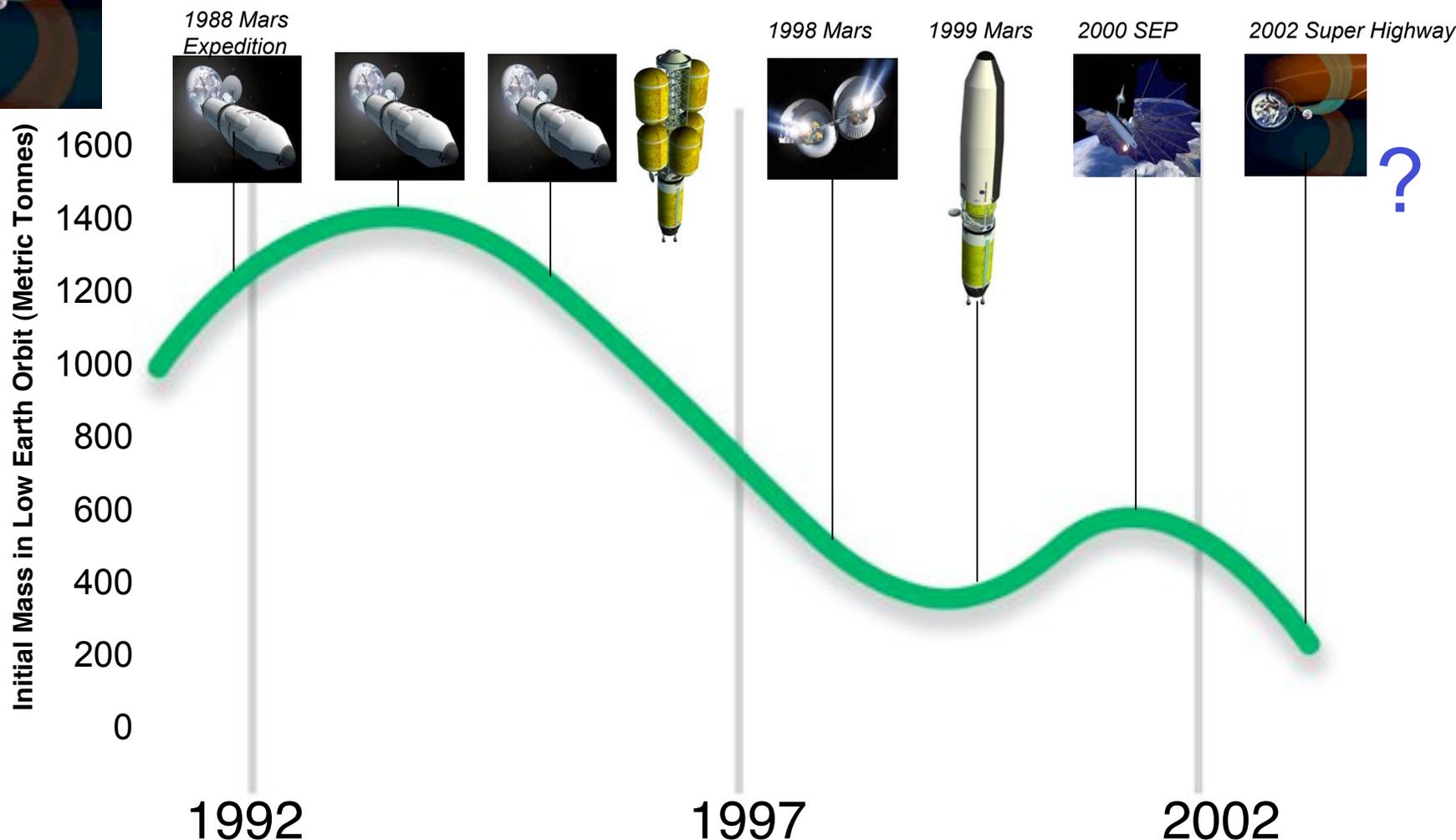




Mars Architecture Progress in Reducing Mass/Cost



- Since 1988 there has been substantial progress to reduce the amount of mass/cost required for missions to Mars



* Initial Mass in Low Earth Orbit (Metric Tons)