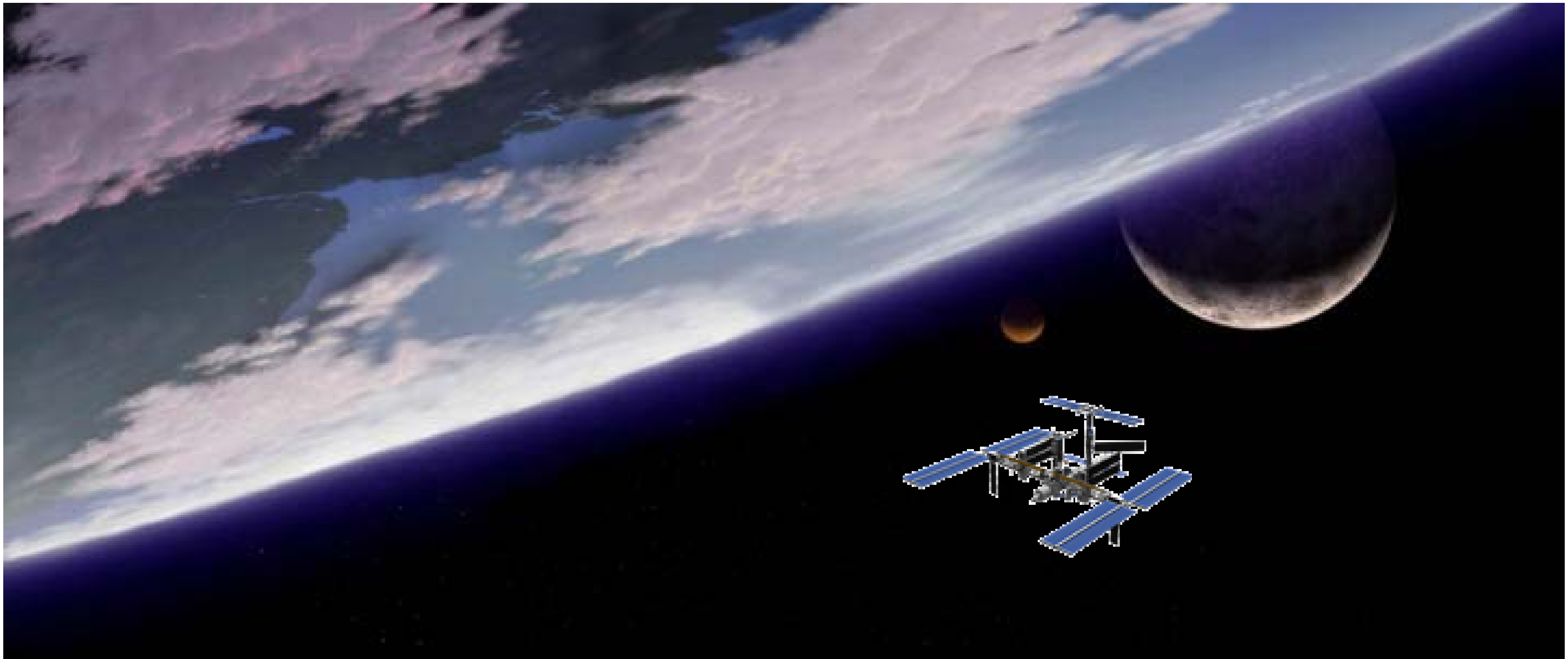


Strategic Architectural Approaches at NASA

MIT

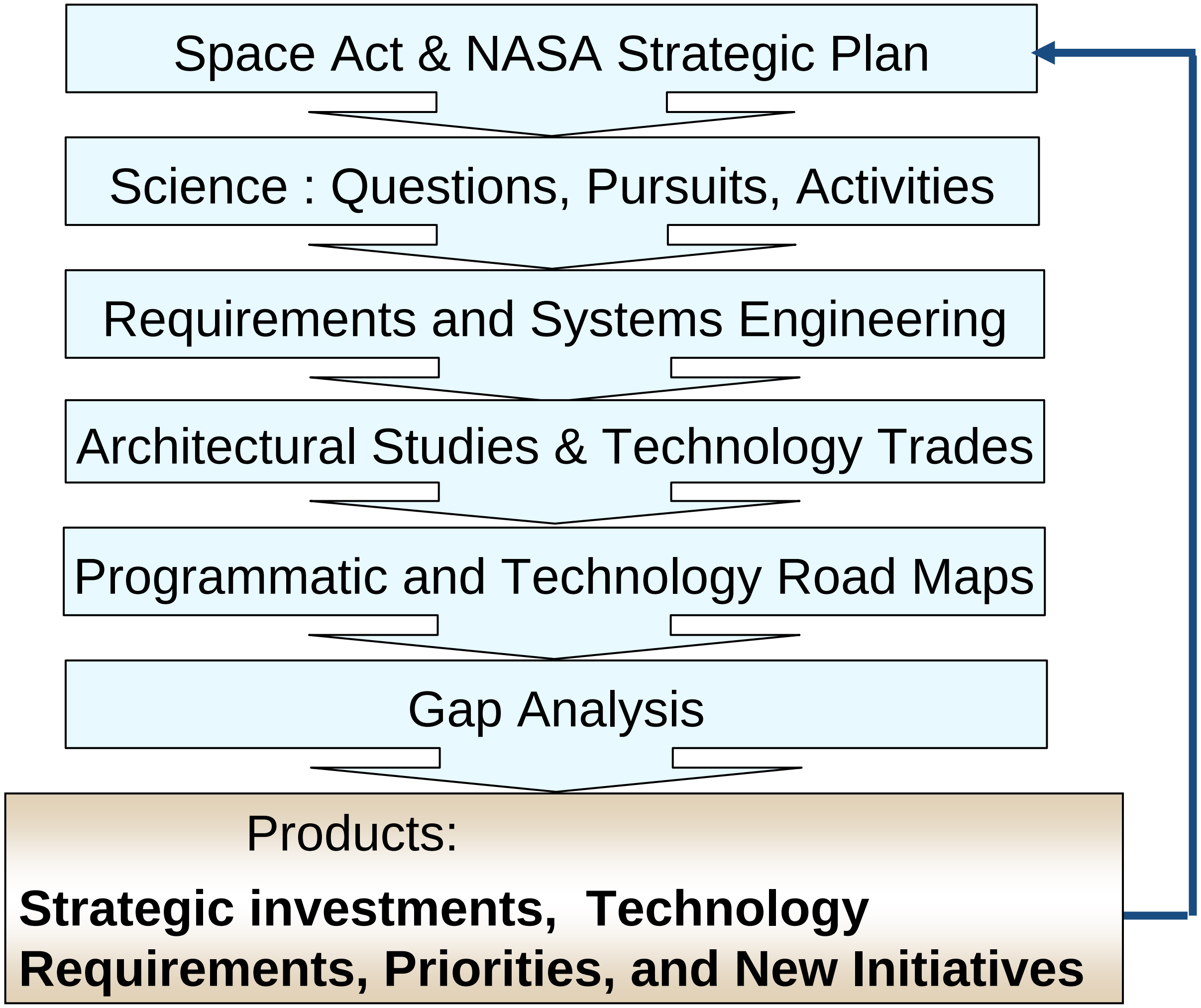
Gary Martin
November 14, 2004

Overview

- **Decadal Planning Team (DPT) /NASA Exploration Team (NEXT)**
- **Space Architect Team/New Vision for Space Exploration**
- **Advanced Planning and Integration Office**
- **A Few Points to Remember**

Decadal Planning Team (DPT) /NASA Exploration Team (NEXT)

Decadal Planning Team/NASA Exploration Team 1999-2002 Process



Space Act & NASA Strategic Plan

Science : Questions, Pursuits, Activities

Requirements and Systems Engineering

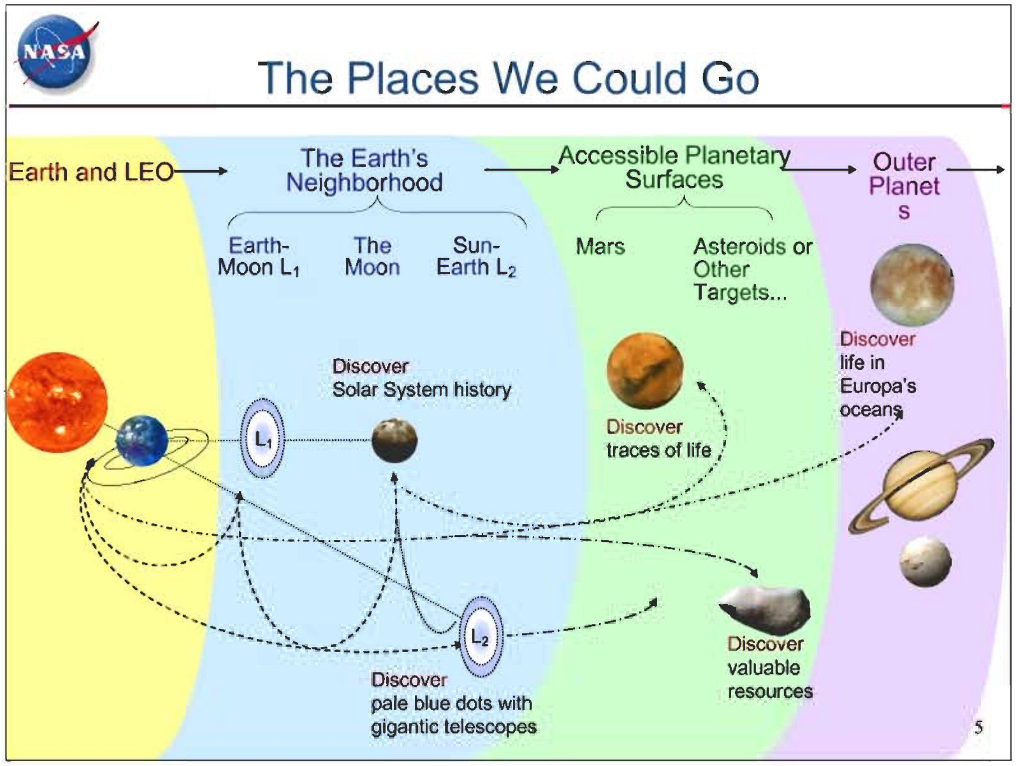
Architectural Studies & Technology Trades

Programmatic and Technology Road Maps

Gap Analysis

Products:

Strategic investments, Technology Requirements, Priorities, and New Initiatives



The Places We Could Go

Earth and LEO → The Earth's Neighborhood → Accessible Planetary Surfaces → Outer Planets →

The Earth's Neighborhood: Earth-Moon L_1, The Moon, Sun-Earth L_2

Accessible Planetary Surfaces: Mars, Asteroids or Other Targets...

Discover Solar System history

Discover traces of life

Discover life in Europa's oceans

Discover pale blue dots with gigantic telescopes

Discover valuable resources

the index to where we must go… anytime and ultimately with humans and machines together, intimately working

Reminder Points:

-Use as index to 3 color coded stepping stones; pushing the human frontier; ultimately anywhere, anytime

-”The Earth’s…” - 1st step

-”Accesable Planetary…” - 2nd step

-”Outer planets” - 3rd step

-history of cosmic collisions 7 the stuff of our solar system

-color-coded again

Stepping Stones

Go anywhere, anytime

Sustainable Planetary Surfaces
Going Beyond and Staying

- Traveling out to ~1.5 AU, and beyond
- Staying for indefinite periods
- Enabling sustainable scientific research
- Living and working on another planet

Accessible Planetary Surfac
Going for Visits

- Traveling out to 1.5 AU
- Staying for 1-3 years
- Enabling tactical investigations
- Visiting and working on another planet

Earth's Neighborhood
Getting Set by Doing

- Traveling up to 1.5 million km
- Staying for 50-100 days
- Enabling huge optical systems
- Living in deep space

Earth and LEO
Getting Ready

- Space Station experience
- Solar System learning
- Technology advancements

Reminder Points:

-Thresholds & attributes; defintions

-Cascade of farther reaching capabilities in time, space & activities

-"Now" - within Van Allen belts; 8x3 = 24 humans x 10 days

-"Enabling huge…" - & microwave

-"Living in deep…" - global lunar access

-"Enabling tactical…" - robotically defined

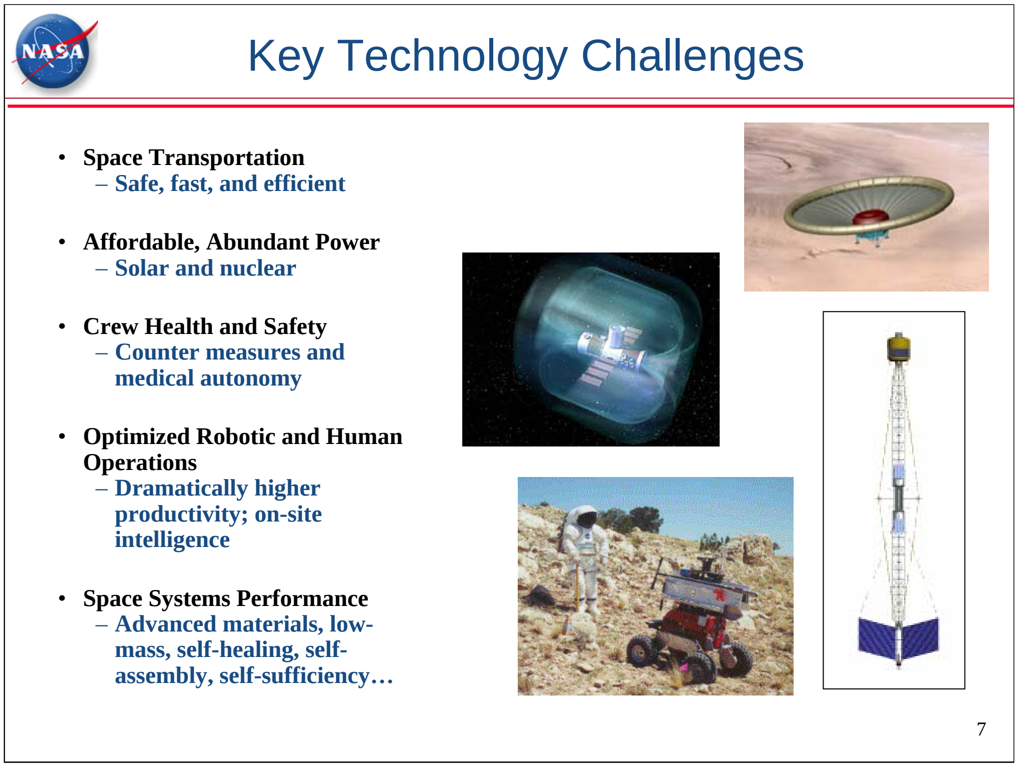
-"Visiting and working…" - or NEO; & sharing the adventure

-using surface as natural space stations

-robotic frontier

-Total Deep Space: Apollo 8, Apollo 10, 12 on Surface, Apollo 11, 12, 13, 14, 15, 16, 17

-100 days exposure, 27 people x 4-10



Key Technology Challenges

- **Space Transportation**
  - **Safe, fast, and efficient**
- **Affordable, Abundant Power**
  - **Solar and nuclear**
- **Crew Health and Safety**
  - **Counter measures and medical autonomy**
- **Optimized Robotic and Human Operations**
  - **Dramatically higher productivity; on-site intelligence**
- **Space Systems Performance**
  - **Advanced materials, low-mass, self-healing, self-assembly, self-sufficiency…**

Fred’s Chart

• To accomplish the strategy the NEXT identified 5 major hurdles which can be overcome by technology.

- Space Transportation: includes both Earth-to-orbit and In-Space

- Affordable, Abundant Power: for both in-space and planetary surface systems, both robotic and someday human

- Crew Health and Safety: How to live and work in space productively

- Optimized Robotic and Human Operations: How do you decide when to use humans on-site

- Space Systems Performance: a catch-all for required improvements for space systems

• One hurdle (Space Transportation) has received new funding from the in-space initiative and two other hurdles (Affordable, Abundant Power and Crew Health and Safety) may get additional funding in the President’s budget as the Nuclear Power Initiative and the Space Radiation Program

• The hurdles will enable new types of missions. In order to support future missions the NEXT team has identified the criteria that must be satisfied (the list runs in a logical order from top to bottom).

• Transition to next chart: The technology needed to overcome these hurdles and enable new missions is determined in a systematic way. The NEXT is structured to conduct the analysis and drive technology investment

Progressive Exploration Capabilities

Transportation

Power

Robotic and Human Ops

Health and Safety

Space Systems

Earth's Neighborhood Capability

- Current launch systems Payload: 40mt
- In-space propulsion, Isp>1000 sec, high thrust
- Power systems, >200 w/kg
- Integrated Human/ robotic capabilities
- Crew countermeasures for 100 days
- Closure of water/air systems
- Materials, factor of 9
- IVHM - Integrated Vehicle Health Monitoring

Accessible Planetary Surface Capability

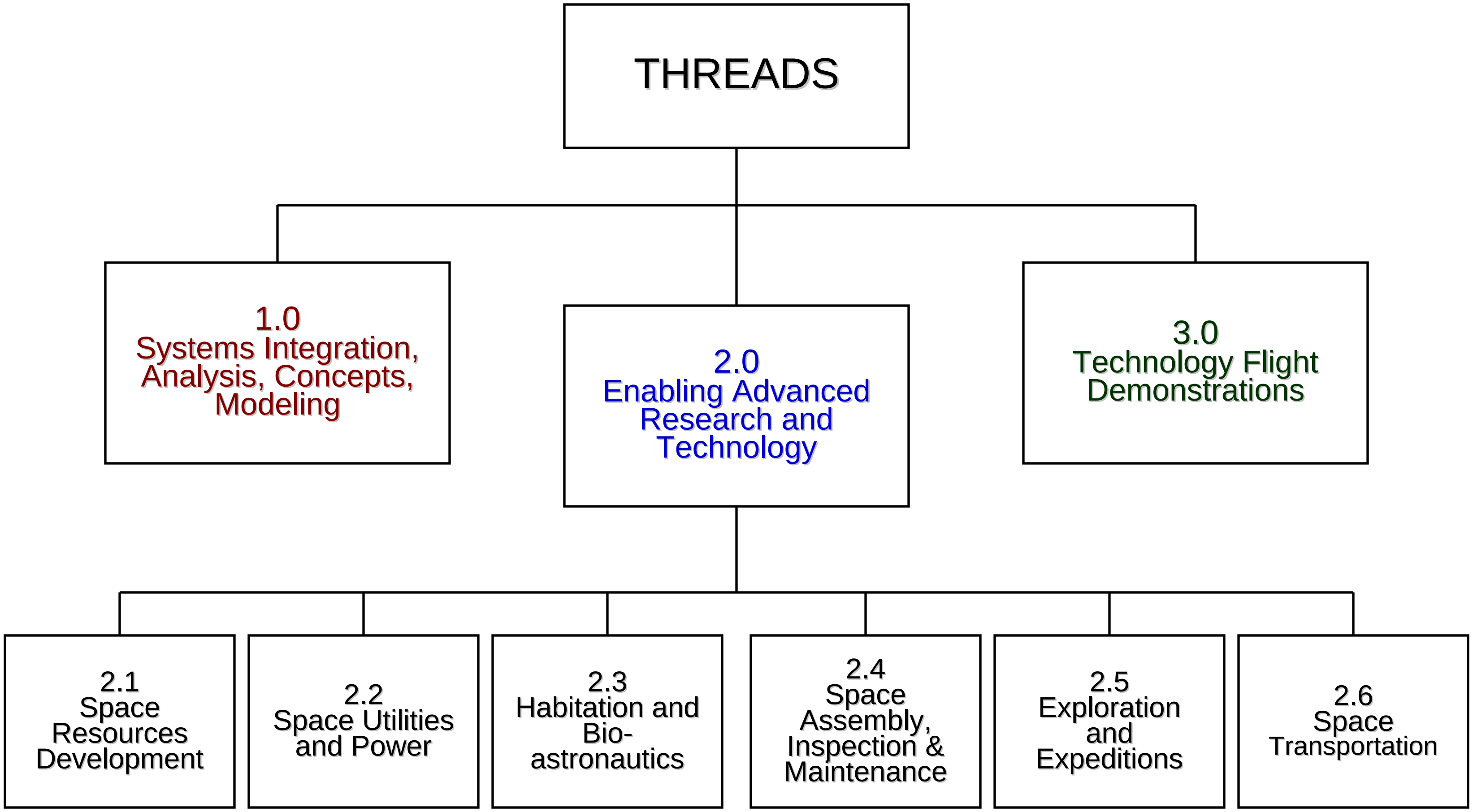
- ETO $/kg (under review) Payload: ~100mt
- In-space propulsion, Isp>3000 sec, high thrust
- Power systems, >500 w/kg
- Robotic aggregation/assembly
- Crew countermeasures for 1-3 years
- Complete closure of air/water; options for food
- Materials, factor of 20
- Micro-/Nano- avionics

Sustainable Planetary Surface Capability

- ETO $/kg (under review) Payload: 100+mt
- In-space propulsion, Isp>3000 sec, high thrust
- Sustainable power systems
- Intelligent systems, orbital and planetary
- Crew countermeasures for indefinite duration
- Closure of life support, including food
- ISRU for consumables & spares
- Materials, factor of 40
- Automated reasoning and smart sensing

Now **2010+** **2020+** **2030+**

Work Breakdown Structure



THREADS

1.0
Systems Integration, Analysis, Concepts, Modeling

2.0
Enabling Advanced Research and Technology

3.0
Technology Flight Demonstrations

2.1
Space Resources Development

2.2
Space Utilities and Power

2.3
Habitation and Bio-astronautics

2.4
Space Assembly, Inspection & Maintenance

2.5
Exploration and Expeditions

2.6
Space Transportation

An Agency-Wide Approach

THREADS

Enterprises...	1.0 Systems Integration, Analysis, Concepts, Modeling	2.0 Enabling Advanced Research and Technology	3.0 Technology Flight Demonstrations
Human Exploration and Development of Space	• HEDS Technology & Commercialization Initiative (HTCI)	• HEDS Technology & Commercialization Initiative • SOMO R&T	• HTCI • Space Shuttle Upgrades
Space Science Enterprise	• Advanced Mission Studies • Cross Enterprise Exploration Team	• Mars Exploration Technology • ASTEP Program(s) • New Millennium Program • Gossamer S/C • ISTP	• New Millennium Program • Data from Robotic Mars Missions/Experiments
Biological and Physical Research Enterprise		• Advanced Human Support Technology • Biomedical Research and Countermeasures • Physical Sciences Research	
Aero-Space Technology Enterprise	• Revolutionary Aerospace Systems Concepts (RASC) / NASA Institute for Aerospace Concepts (NIAC) • ISE Collaborative Engineering Environment & Costing Tools	• Space R&T Base (incl. NRAs) • Intelligent Systems • ISTP • SLI • SBIR supporting (THREADS)	• In-Space Transportation Technology Program (ISTP) • *Space Launch Initiative (SLI--coordination)*
Earth Science Enterprise	• ES Vision Technologies • Advanced Mission Concepts	• Instrument Incubator Program • Advanced Technology Initiative • Advanced Information Systems Technology	• New Millenium Program (EO-X)

Top-10 R&D Areas

Earth Neighborhood

- √ **Biological Risk (Radiation)**
- √ **Space Solar Power (High Power)**
- √ **Space Assembly, Maintenance & Servicing (Robotic, EVA)**
- √ **Cryogenic Propellant Depots**
- x Aero- Assist/Entry and Landing
- x Electric/Electromagnetic Propulsion (High Power)
- x Adaptation and Countermeasures (Gravity)
- x Communications and Control
- x Human Factors and Habitability

Accessible Planetary

- √ **Regenerative Life Support Systems**
- √ **Surface Science & Mobility** (Human-Involved)
- √ **Materials and Structures** (Manufacturing Validation)
- x Space Medicine and Health Care
- x Earth-to-Orbit Transportation
- x In-Space Chemical Propulsion
- x Nuclear Propulsion

Sustained Planetary Surface

- √ **Advanced Habitation Systems**
- x Space Nuclear Power
- x In Situ Resource Utilization
- x In Situ Manufacturing
- x Flying Systems

The Top-10

- √ **Biological Risk (Radiation)**
- √ **Space Power (High Power)**
- √ **Space Assembly, Maintenance & Servicing (Robotic, EVA)**
- √ **Regenerative Life Support**
- √ **Surface Science & Mobility Systems**
- √ **Cryogenic Propellant Depots**
- √ **Materials and Structures (Mfg)**
- √ **Advanced Habitation Systems**

PLUS…

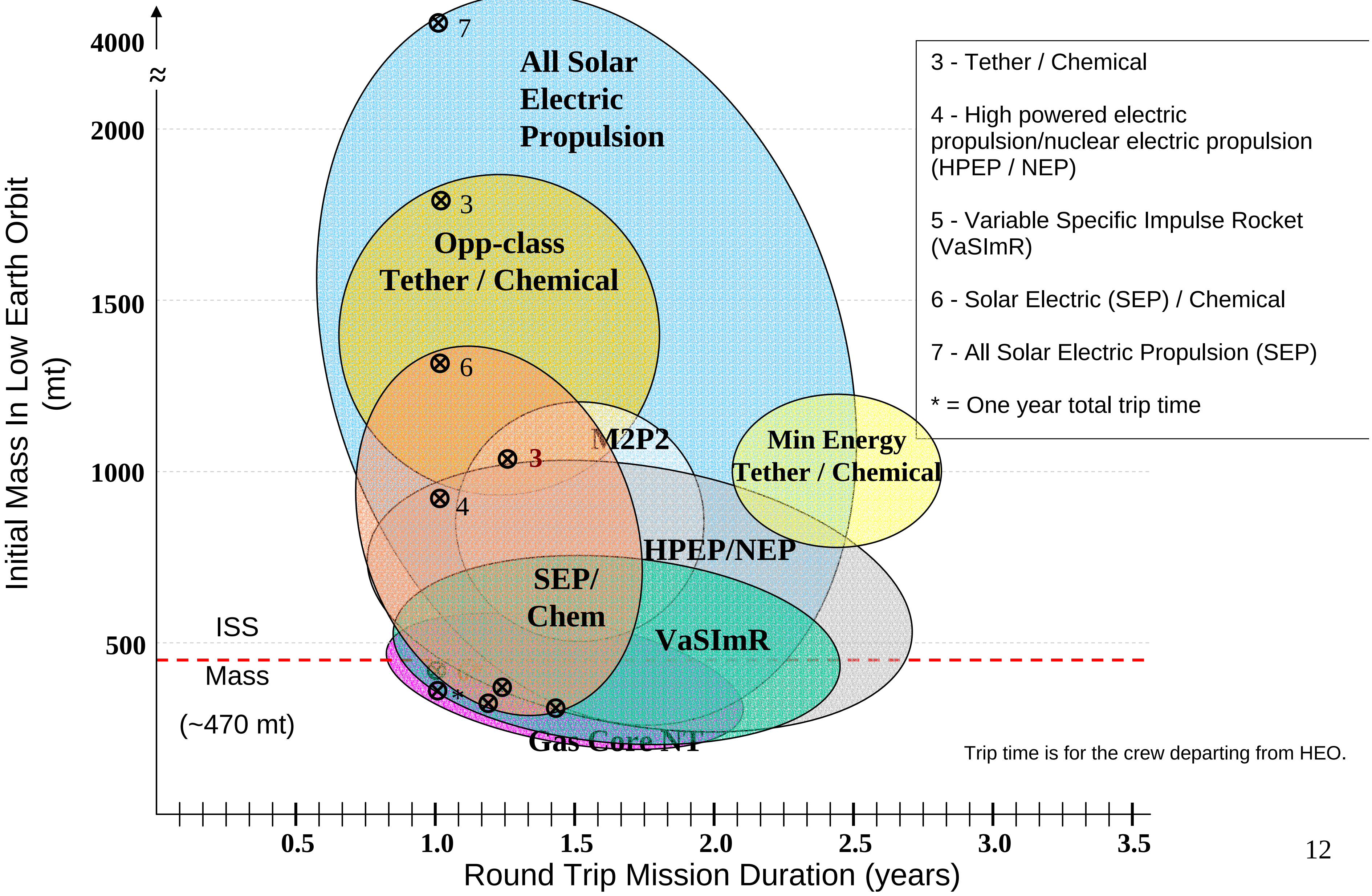
- √ **Systems Studies, Advanced Concepts, etc.**
- √ **Technology Flight Demos**

📄 Requires additional funding in FY’02

🗄 Important, but does not require additional funding at this time

In-Space Transportation

Example: Interplanetary Transportation Options



3 - Tether / Chemical

4 - High powered electric propulsion/nuclear electric propulsion (HPEP / NEP)

5 - Variable Specific Impulse Rocket (VaSImR)

6 - Solar Electric (SEP) / Chemical

7 - All Solar Electric Propulsion (SEP)

* = One year total trip time

Trip time is for the crew departing from HEO.

Agency Investments

Prioritized In-Space Propulsion Technologies

Process

- Requirements/Goals Established by NASA Enterprises

↓

- Technology options identified

↓

- Systems concepts developed

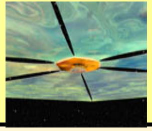
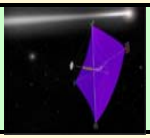
↓

- Systems Concepts Compared

↓

- Technologies Prioritized

🟨 Code S Priority
🟩 Code M Priority
🟦 Code M and S

In-Space Propulsion Technology	High Priority	Medium Priority	Low Priority	High Payoff/ High Risk
Advanced Chemical		🟦 		
Aerocapture	🟦 			
Solar Electric Propulsion (SE	🟦 			
Nuclear Electric Propulsion (NE	🟦 			
Solar Sails	🟨 		🟩 	
Solar Thermal		🟩 		
Nuclear Thermal Propulsion (Bimodal)		🟩 		
Plasma Sails				🟦 
Momentum Exchange Tethers (MXER)				🟦 

Crew Health and Safety

Radiation Research

Recommendations for effective dose limits (Sv*) for 3% excess cancer fatality for 10 year careers

	Female		Male	
Age	1990	2000	1990	2000
25	1.0	0.4	1.5	0.7
35	1.8	0.6	2.5	1.0
45	2.5	0.9	3.2	1.5
55	3.0	1.7	4.0	3.0

Age at First Mission	No. of 180-day LEO missions**	
	Female	Male
25	0	1
35	1	1
45	1	2
55	2	3

Considerations

- Costs of training
- Costs of crew replacement
- Career corps vs one-mission astronauts

* 1 SV = 100 REM. 1 REM = measure of effective biological damage as determined by absorbed dose x quality factor

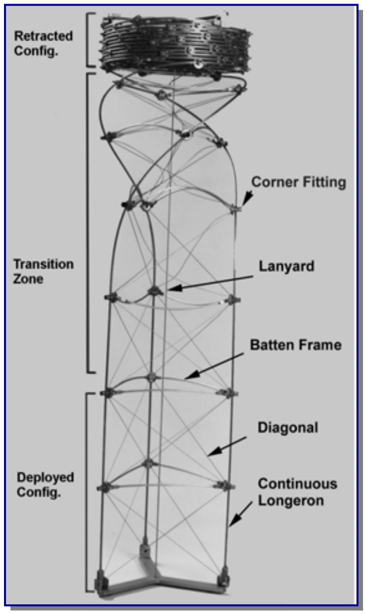
** Administrative limits: 1% risk excess cancer risk; 0.2 Sv/mission; no uncertainty assumed.

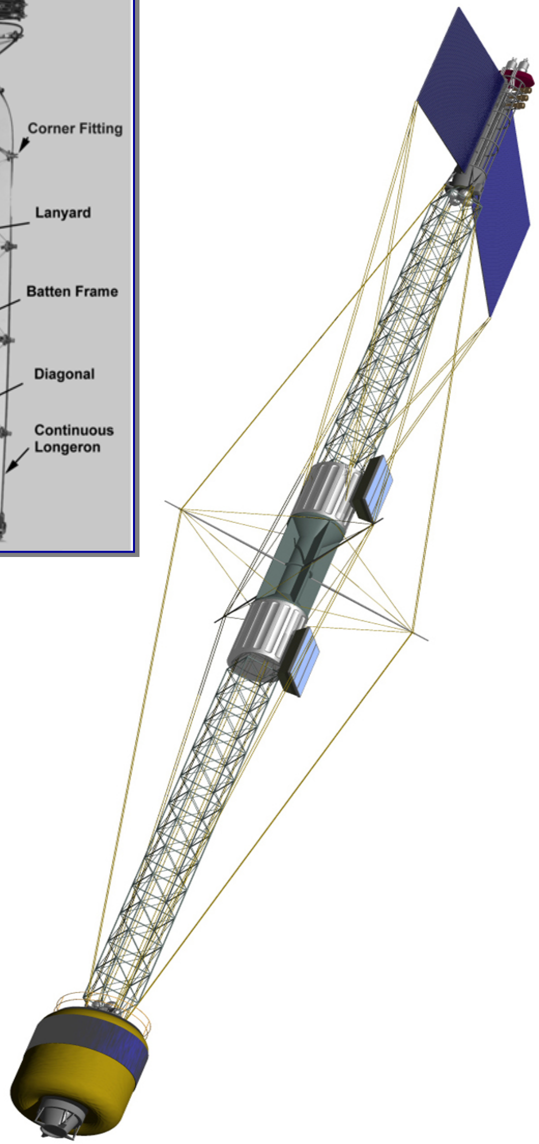
Report Available - Space Radiation Cancer Risk Projections

Hurdles: Crew Health & Safety

Artificial Gravity NEP Vehicle System Concepts

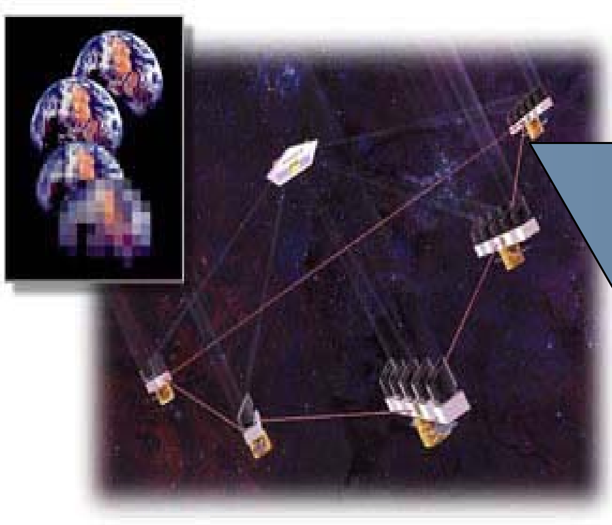
- **Objective**
  - Develop and assess integrated NEP and artificial gravity (AG) vehicle systems concepts as a means to mitigate the deleterious effects of zero gravity on humans
- **Methodology**
  - 1-g, 4 rpm system – consistent with human centrifugation tests
  - Minimize AG vehicle mass “penalties” & complexity
  - 18-month Mars roundtrip, nuclear electric propulsion
- **Assessments**
  - AG crew hab module design assessment
  - Power/propulsion/trajectory trades
  - Angular momentum management/vehicle steering strategies
  - Preliminary assessment of structural, power system designs
- **Results**
  - Only small dry mass AG penalties identified (< 5%)
  - Good synergy among power system and propulsive performance
  - Propellant-efficient steering strategies identified





Human/Robotic Partnership

Optimizing the Human/Robotic Equation



- Technology Projections
- Experience and Lessons Learned
- Mission Performance Assessments

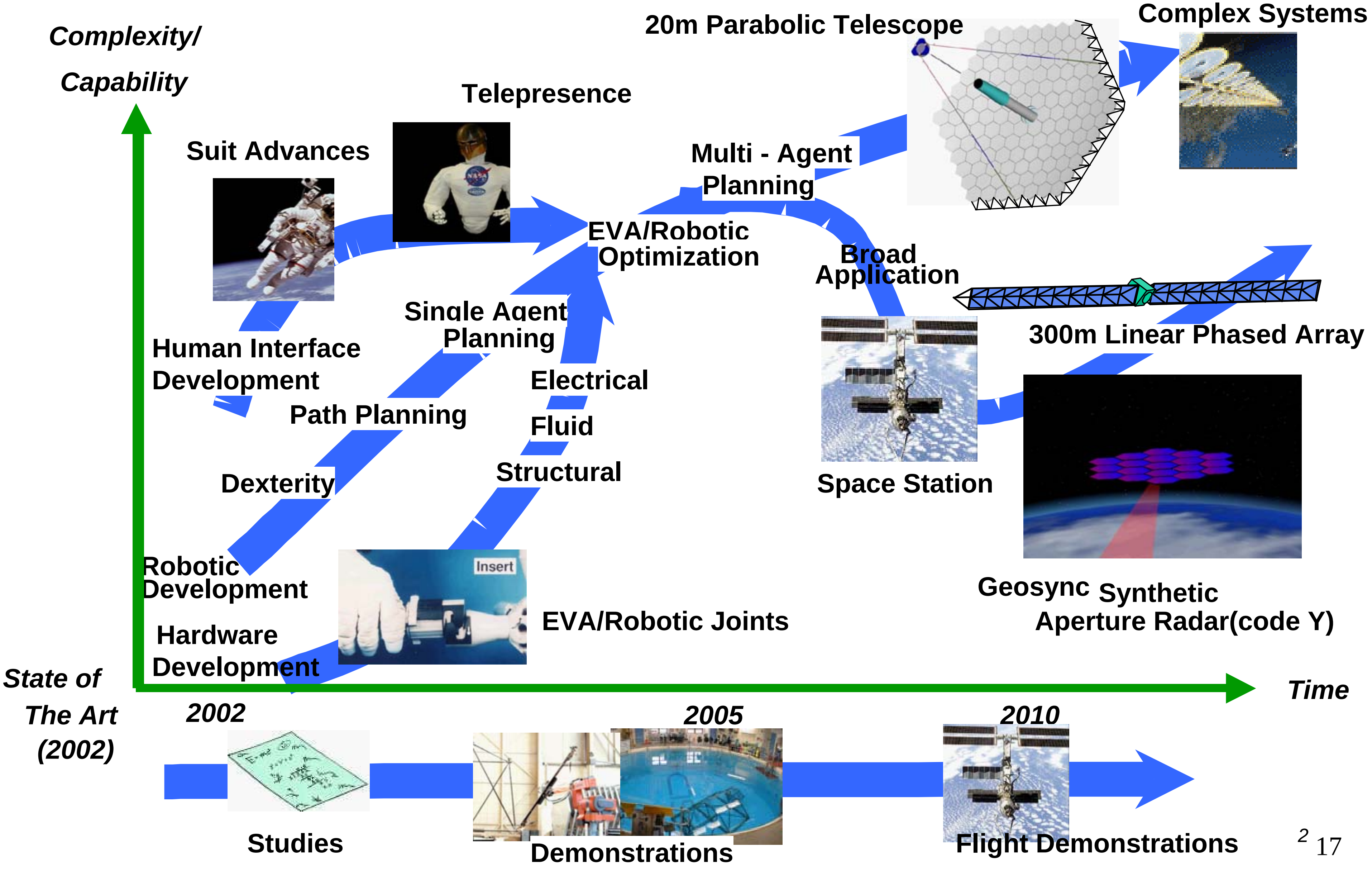
Optimal Human and Robotic Combinations

Example Science Activities

Creating science instruments and observing platforms to search for life sustaining planets

Search for evidence of life on planetary surfaces

Large Space Telescope Construction and Maintenance



Complexity/

Capability

Suit Advances

Telepresence

20m Parabolic Telescope

Complex Systems

Multi - Agent Planning

EVA/Robotic Optimization

Broad Application

Single Agent Planning

Human Interface Development

300m Linear Phased Array

Electrical

Path Planning

Fluid

Structural

Dexterity

Space Station

Robotic Development

Hardware Development

EVA/Robotic Joints

Geosync Synthetic Aperture Radar(code Y)

State of The Art (2002)

Time

2002

2005

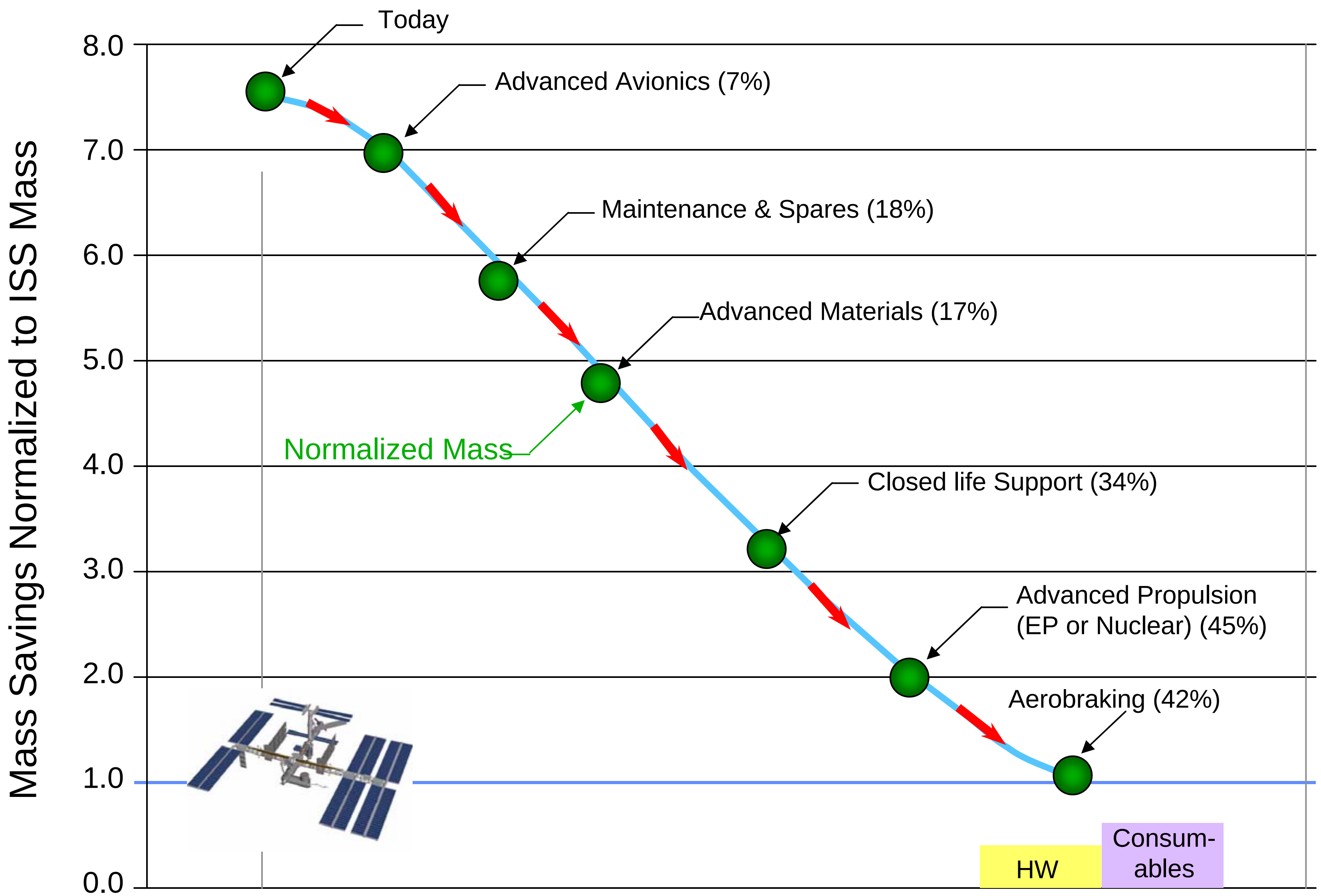
2010

Studies

Demonstrations

Flight Demonstrations

Space Systems
Example: Mars Human Mission

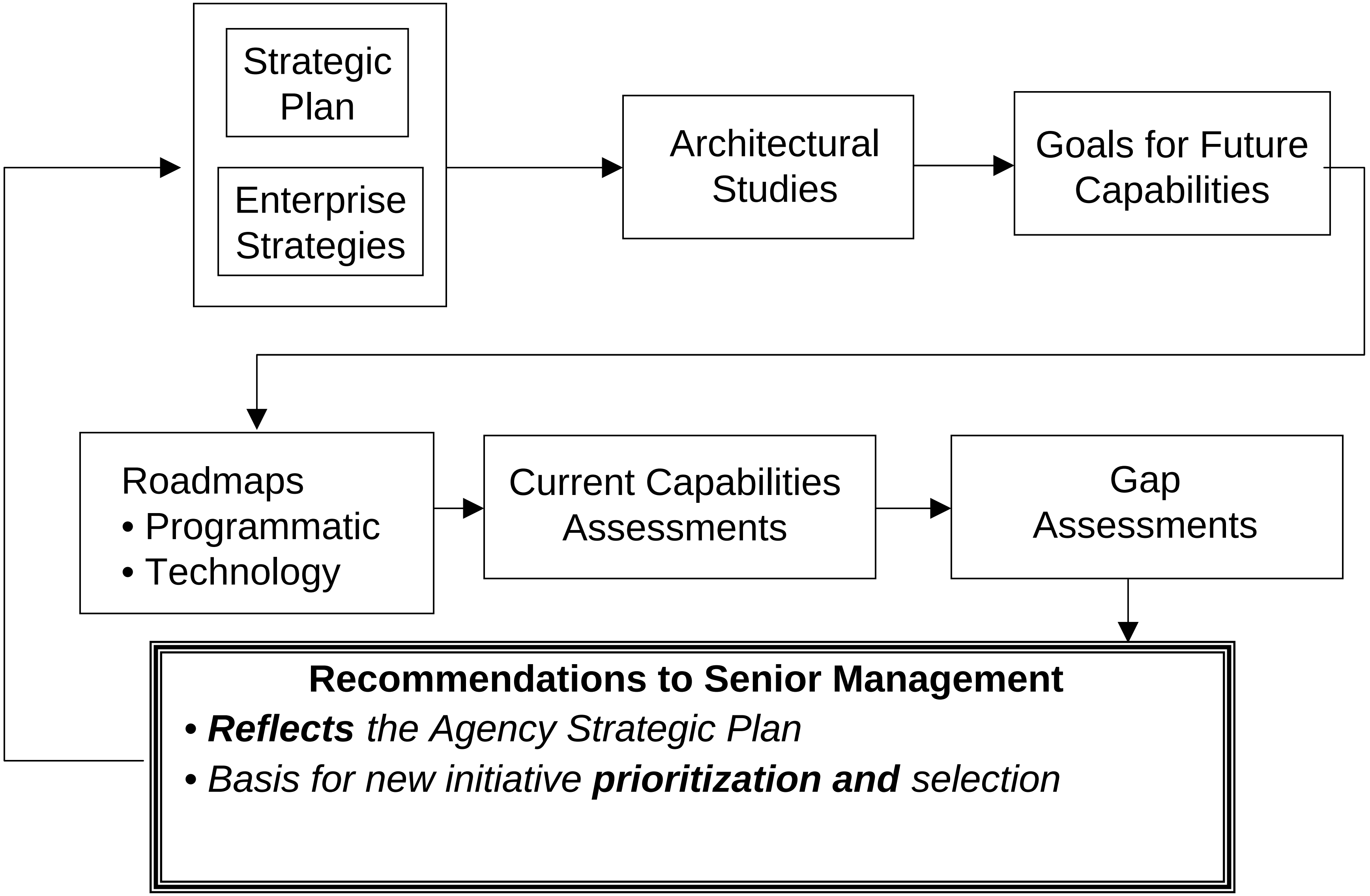


Space Architect Team/New Vision for Space Exploration

Architecture Studies

- Architectures are used to:
  - **Understand requirements for exploration in the context of other space missions and research and development programs**
  - **Establish an end-to-end mission baseline against which other mission and technology concepts can be compared**
  - **Derive enabling and enhancing capability needs**
  - **Derive technology research and development plans**
  - **Define and prioritize requirements**
  - **Define and prioritize flight experiments**
- Comparing architectures specific measures of merit;
  - **Safety**
  - **Cost**
  - **Performance**
  - **Mission return**
  - **Schedule**

Space Architecture Planning Process



Strategic Plan

Enterprise Strategies

Architectural Studies

Goals for Future Capabilities

Roadmaps
- Programmatic
- Technology

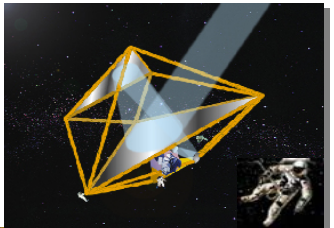
Current Capabilities Assessments

Gap Assessments

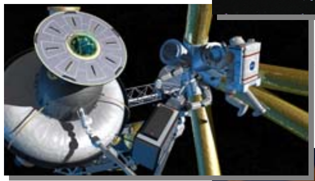
Recommendations to Senior Management
- ***Reflects** the Agency Strategic Plan*
- *Basis for new initiative **prioritization and** selection*

Architecture Study #1 Focus

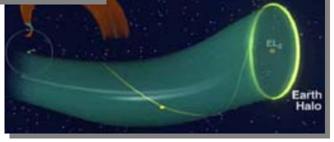
- **Assemble and Service Large Astronomical Facilities**
  - Evaluate options for the assembly and deployment of large, complex science facilities
  - Understand how humans and robots, working together in an optimum way, can build and service the next generation of space facilities
  - Develop mission architectures using the Earth's Neighborhood L-points to support this activity
- **Lunar Exploration**
  - Study how lunar exploration scenarios fit into mission strategies for assembly and deployment of large science platforms in space
- **Artificial Gravity Transfer Vehicle**
  - Demonstrate preliminary engineering feasibility of a nuclear propulsion, artificial-gravity (AG), interplanetary human exploration spacecraft



Large Infrared Telescope

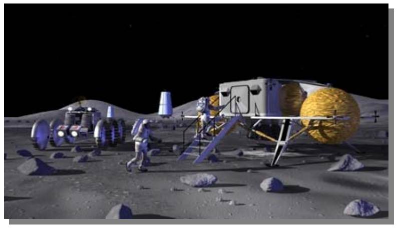


Science Platform Servicing



Mission Architectures

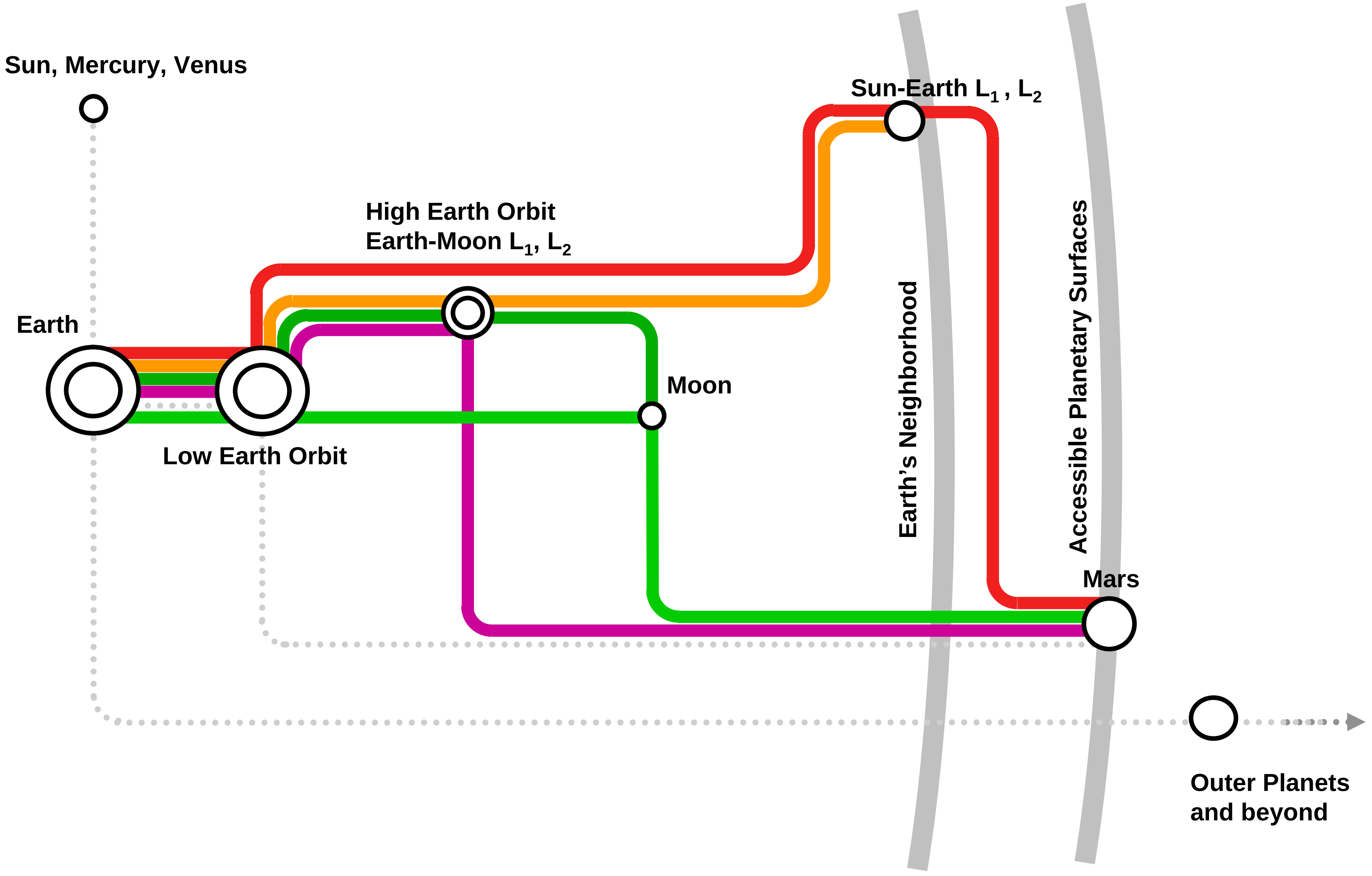
Return to the Moon



Artificial-g Mars Transfer Vehicle

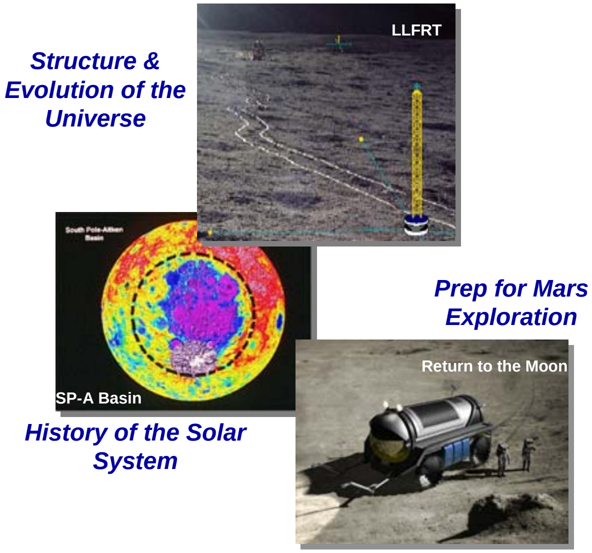
Architecture Study #1

Exploration Metro Map

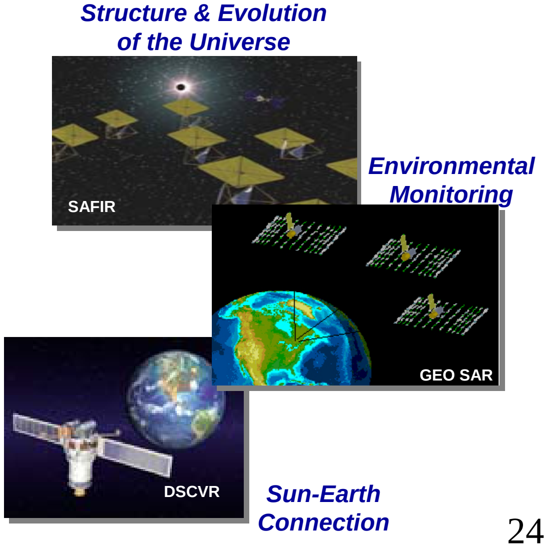


Architecture Study #2 Focus

- **Multi-Enterprise Lunar Surface Exploration**
  - Lunar surface biological research
  - Ops preparation for human Mars exploration
  - South Pole-Aitken Basin sample return
  - ISRU identification and assessment
  - South Pole observation station
  - Opportunistic lunar science

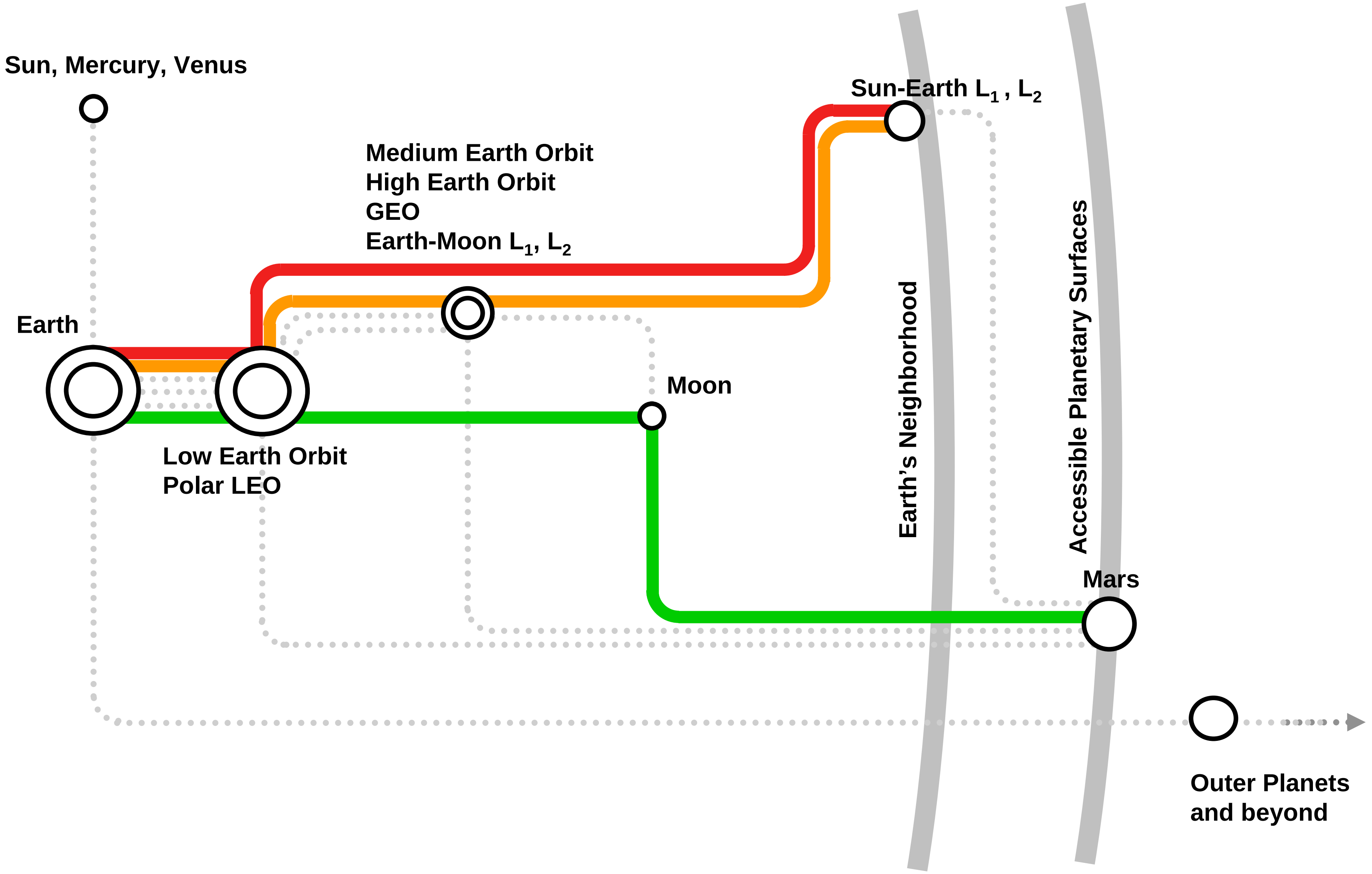


- **Large Science Platforms in Space**
  - Consider large platform needs for all major science enterprises
  - Consider multiple destinations
    - LEO, Polar LEO, MEO, GEO, Earth-Moon L-Points, Lunar Surface, Sun-Earth L-Points
  - Include robust capabilities for in-space assembly, repair, and servicing by humans and robots
  - Study system interoperability and commonality for platform access and transportation needs



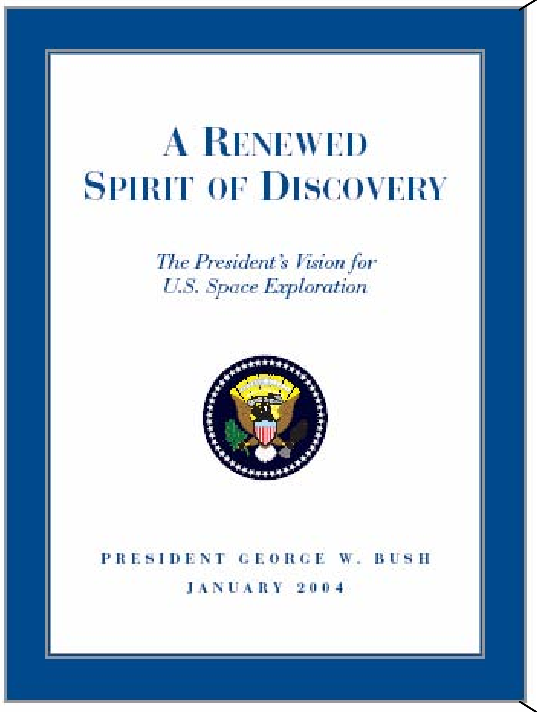
Architecture Study #2

Exploration Metro Map



National Vision for Space Exploration

THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM



A RENEWED
SPIRIT OF DISCOVERY

The President's Vision for
U.S. Space Exploration

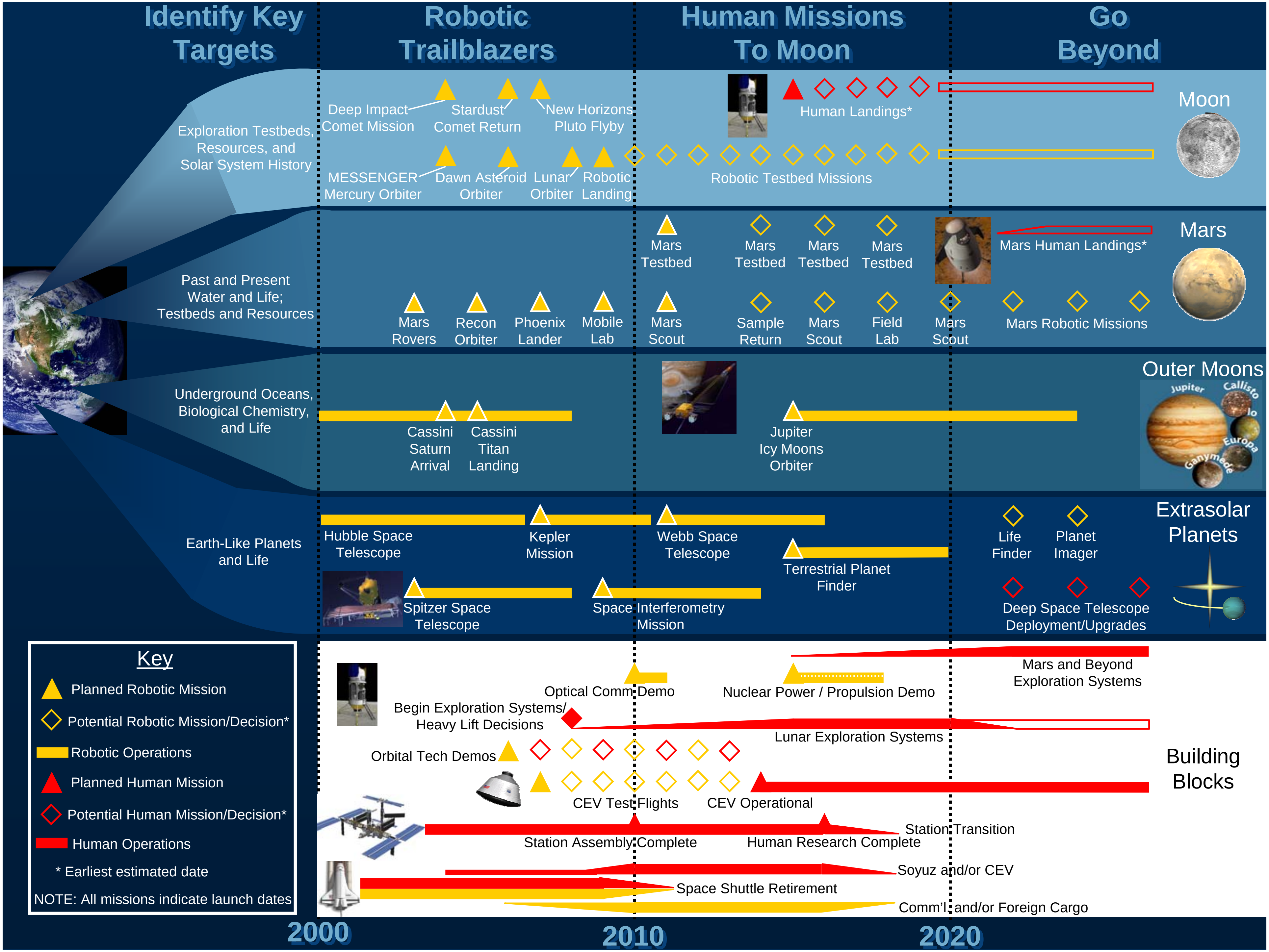
PRESIDENT GEORGE W. BUSH
JANUARY 2004

Implement a sustained and affordable human and robotic program to explore the solar system and beyond

Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.



Identify Key Targets

Robotic Trailblazers

Human Missions To Moon

Go Beyond

Moon

Exploration Testbeds, Resources, and Solar System History

Deep Impact Comet Mission
Stardust Comet Return
New Horizons Pluto Flyby
Human Landings*
MESSENGER Mercury Orbiter
Dawn Asteroid Orbiter
Lunar Orbiter
Robotic Landing
Robotic Testbed Missions

Mars

Past and Present Water and Life; Testbeds and Resources

Mars Testbed
Mars Testbed
Mars Testbed
Mars Testbed
Mars Human Landings*
Mars Rovers
Recon Orbiter
Phoenix Lander
Mobile Lab
Mars Scout
Sample Return
Mars Scout
Field Lab
Mars Scout
Mars Robotic Missions

Outer Moons

Underground Oceans, Biological Chemistry, and Life

Cassini Saturn Arrival
Cassini Titan Landing
Jupiter Icy Moons Orbiter

Extrasolar Planets

Earth-Like Planets and Life

Hubble Space Telescope
Kepler Mission
Webb Space Telescope
Terrestrial Planet Finder
Life Finder
Planet Imager
Spitzer Space Telescope
Space Interferometry Mission
Deep Space Telescope Deployment/Upgrades

Building Blocks

Mars and Beyond Exploration Systems
Optical Comm Demo
Nuclear Power / Propulsion Demo
Begin Exploration Systems/ Heavy Lift Decisions
Lunar Exploration Systems
Orbital Tech Demos
CEV Test Flights
CEV Operational
Station Transition
Station Assembly Complete
Human Research Complete
Soyuz and/or CEV
Space Shuttle Retirement
Comm'l. and/or Foreign Cargo

Key

- ▲ Planned Robotic Mission
- ◇ Potential Robotic Mission/Decision*
- ▬ Robotic Operations
- ▲ Planned Human Mission
- ◇ Potential Human Mission/Decision*
- ▬ Human Operations

* Earliest estimated date

NOTE: All missions indicate launch dates

2000 2010 2020

Level 0 Exploration Requirements

Mission Statement

NASA shall advance U.S. scientific, technological, security, and economic interests through a robust human and robotic space exploration program.

Level 0 Exploration Requirements

(1) NASA shall implement a safe, sustained, and affordable robotic and human program to explore and extend the human presence across the solar system and beyond.

- **(1.1) NASA shall develop the innovative technologies, knowledge, capabilities, and infrastructures to support human and robotic exploration.**
- **(1.2) NASA shall conduct a series of robotic missions to the Moon to prepare for and support future human exploration activities.**
- **(1.3) NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations.**
- **(1.4) NASA shall conduct robotic exploration of Mars to search for evidence of life, to understand the history of the solar system, and to prepare for future human exploration.**
- **(1.5) NASA shall conduct human expeditions to Mars to extend the search for life and to expand the frontiers of human exploration after successfully demonstrating human exploration mission to the moon.**
- **(1.6) NASA shall conduct robotic exploration across the solar system for scientific purposes and to support human exploration.**
- **(1.7) NASA shall conduct advanced telescope searches for Earth-like planets and habitable environments around other stars.**

Level 0 Exploration Requirements (cont)

(2) NASA shall acquire an exploration transportation system to support delivery of crew and cargo from the surface of the Earth to exploration destinations and to return the crew safely to Earth.

(3) NASA shall complete assembly of the International Space Station, including the U.S. components that support U.S. space exploration goals and components provided by foreign partners, planned by the end of the decade.

- **(3.1) NASA shall focus use of the Space Shuttle to complete assembly of the International Space Station.**
- **(3.2) NASA shall focus U.S. International Space Station research and technology on supporting space exploration goals.**
- **(3.3) NASA shall separate transportation of crew and cargo to the International Space Station to the maximum extent practical.**

(4) NASA shall pursue opportunities for international participation to support U.S. space exploration goals.

(5) NASA shall pursue commercial opportunities for providing transportation and other services supporting the International Space Station and exploration mission beyond low Earth orbit.

(6) NASA shall identify and implement opportunities within missions for the specific purposes of inspiring the Nation.

Notional Architecture

Human Destination: Mars

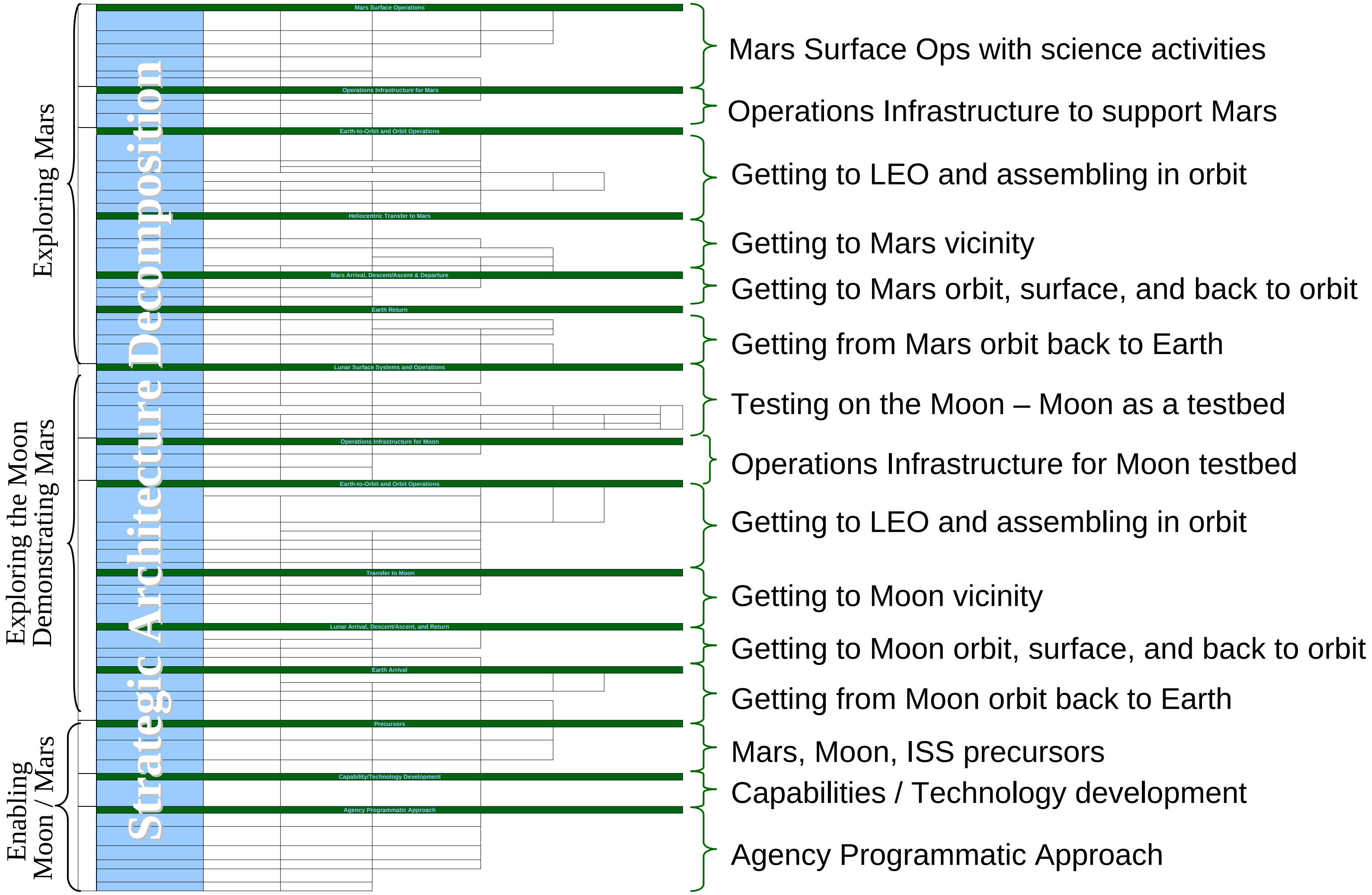
Conceptual Mission Models

- **Conduct Search for Life at Modern Habitats: Implement campaign of "short stay" human-based missions to martian surface (30–90 days) to search for present life at sites determined to be modern habitats**
- **Conduct *Search for Evidence of Ancient Life*: Investigate sedimentary deposits identified previously as an ancient habitat of life through a long surface stay**

- Conduct *Search for Extant Life in Hydrothermal Deposits*: In-situ exploration of an area suspected of harboring underground liquid water as candidate site for evidence of extant life/pre-biotic chemistry
- Explore *Global Evolution of Mars*: Examine initial conditions and investigate why terrestrial planets evolved differently, much more so than we had thought, if no evidence of past or present liquid water has been found

Notional Architecture

Level 0 Architecture Trade Tree



Mars Surface Ops with science activities

Operations Infrastructure to support Mars

Getting to LEO and assembling in orbit

Getting to Mars vicinity

Getting to Mars orbit, surface, and back to orbit

Getting from Mars orbit back to Earth

Testing on the Moon – Moon as a testbed

Operations Infrastructure for Moon testbed

Getting to LEO and assembling in orbit

Getting to Moon vicinity

Getting to Moon orbit, surface, and back to orbit

Getting from Moon orbit back to Earth

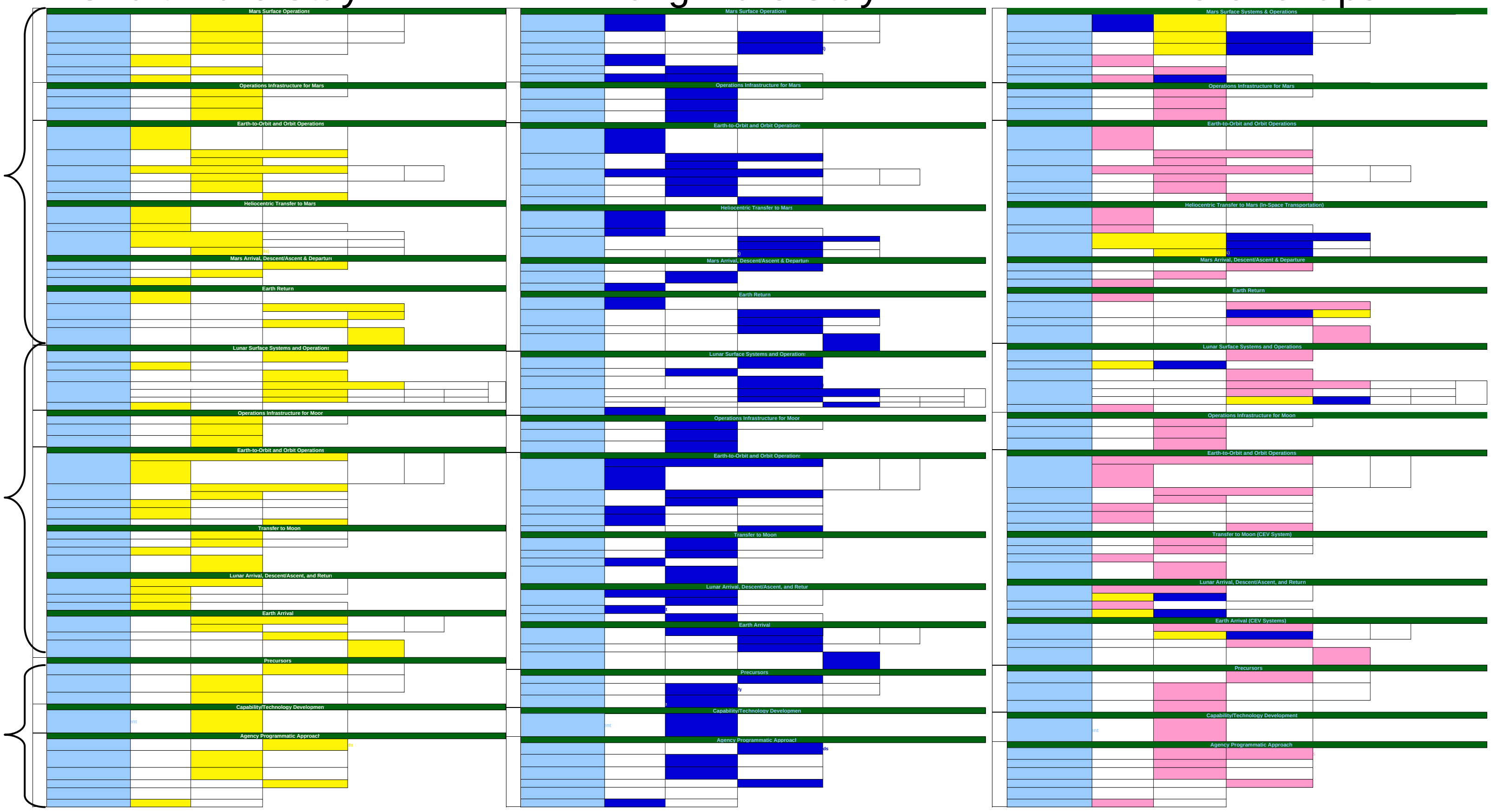
Mars, Moon, ISS precursors

Capabilities / Technology development

Agency Programmatic Approach

Notional Architecture

Trade Space Alternatives



* DRA 1
Short Mars Stay

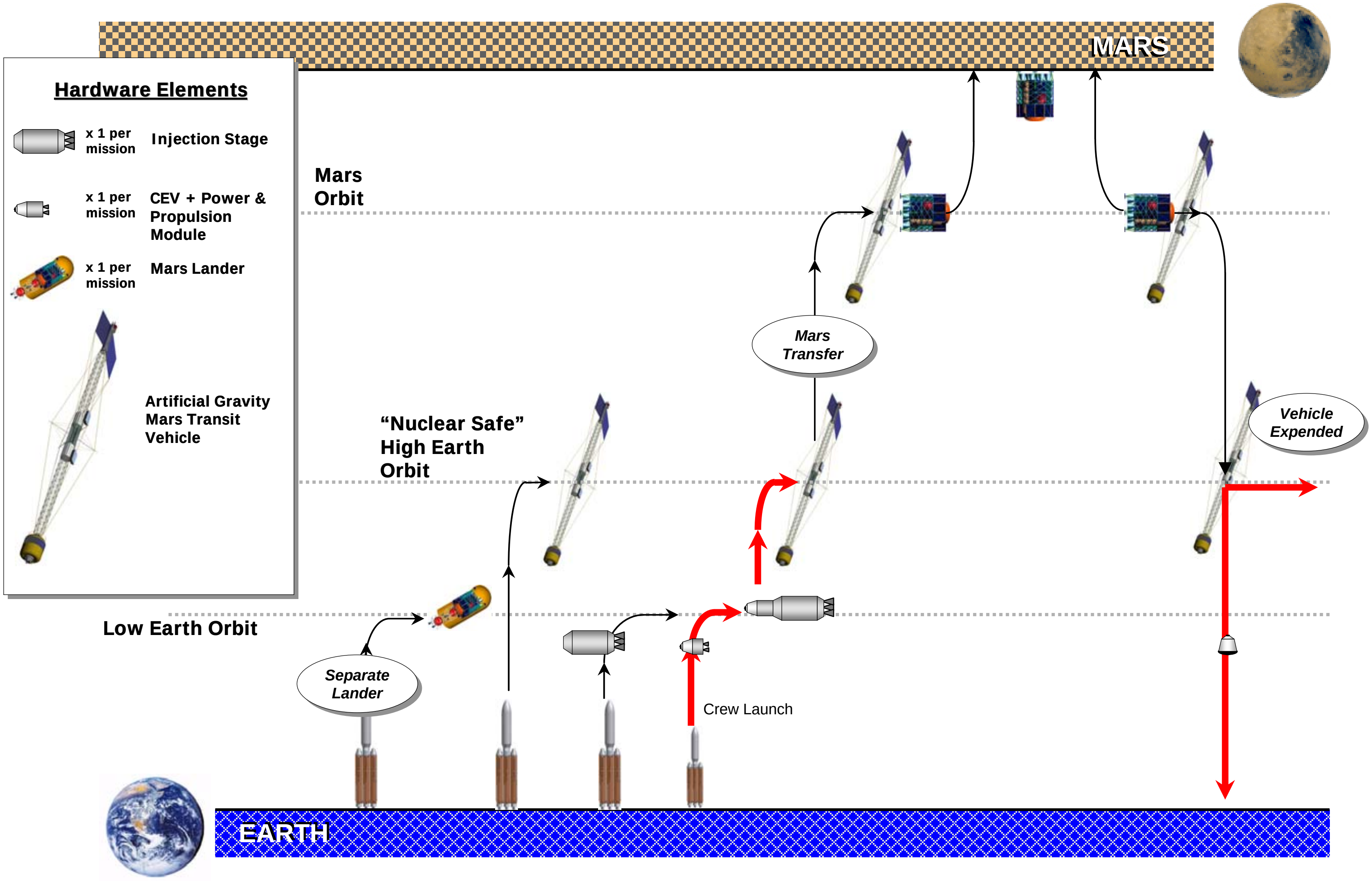
DRA 2
Long Mars Stay

Combined DRAs
IDs Overlaps

* DRA = Design Reference Architecture, which bounds the trade space

Notional Architecture

Notional Mars Operations Concept DRA #1



MARS

Hardware Elements

	x 1 per mission	Injection Stage
	x 1 per mission	CEV + Power & Propulsion Module
	x 1 per mission	Mars Lander
		Artificial Gravity Mars Transit Vehicle

Mars Orbit

"Nuclear Safe" High Earth Orbit

Low Earth Orbit

Mars Transfer

Vehicle Expended

Separate Lander

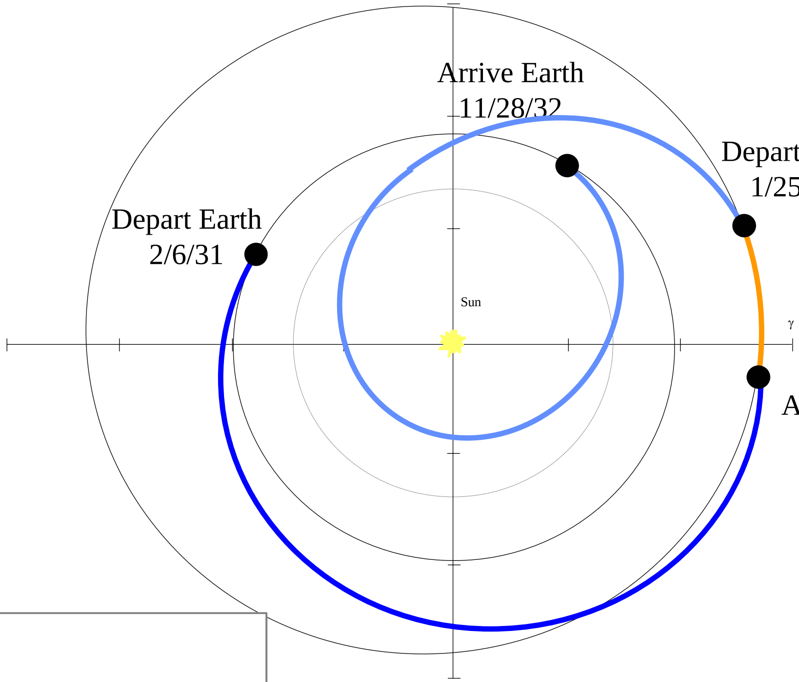
Crew Launch

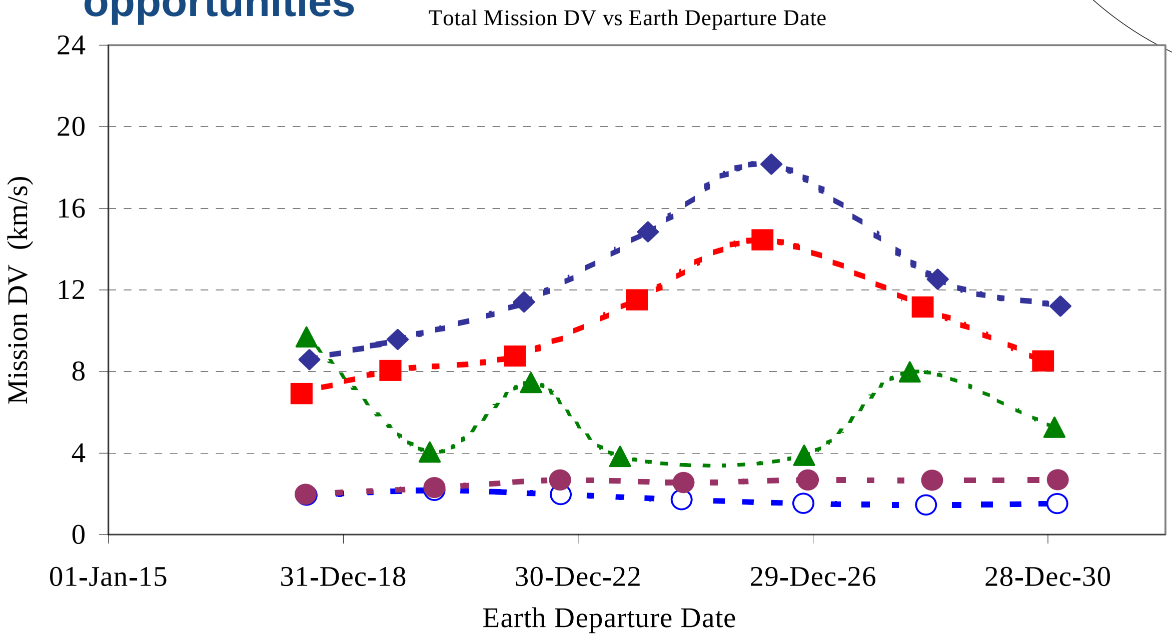
EARTH

Notional Architecture

Example Short-Stay Missions

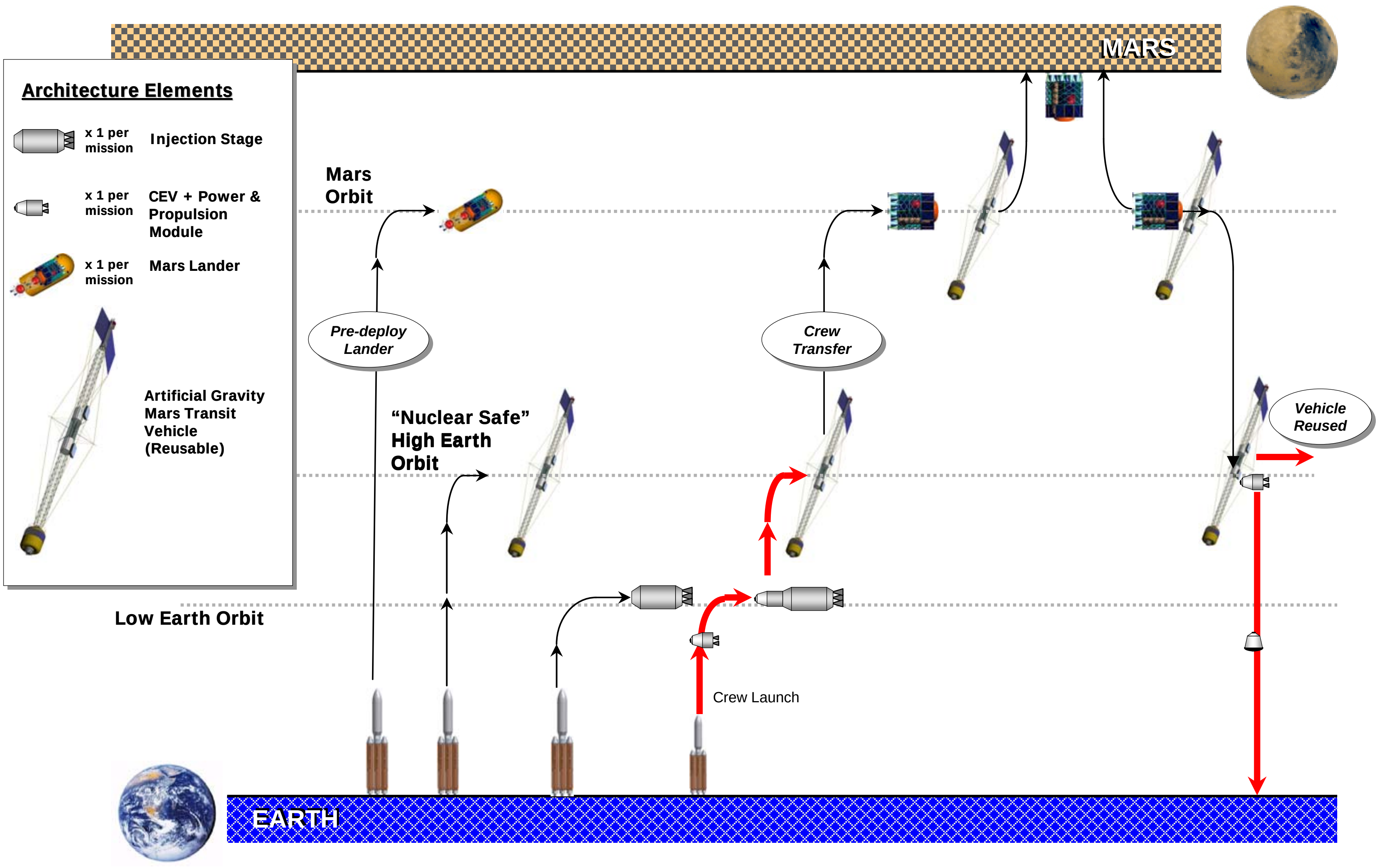
- **Typically referred to as *opposition class* missions**
- **Characterized by**
  - **Only 1 Hohman transfer (short leg)**
  - **High-propulsive requirements for other leg (long leg)**
    - **Venus swing-by or deep-space Maneuvers**
    - **Close perihelion passage**
  - **Large variation in energy requirements across mission opportunities**





Notional Architecture

Notional Mars Operations Concept DRA #2



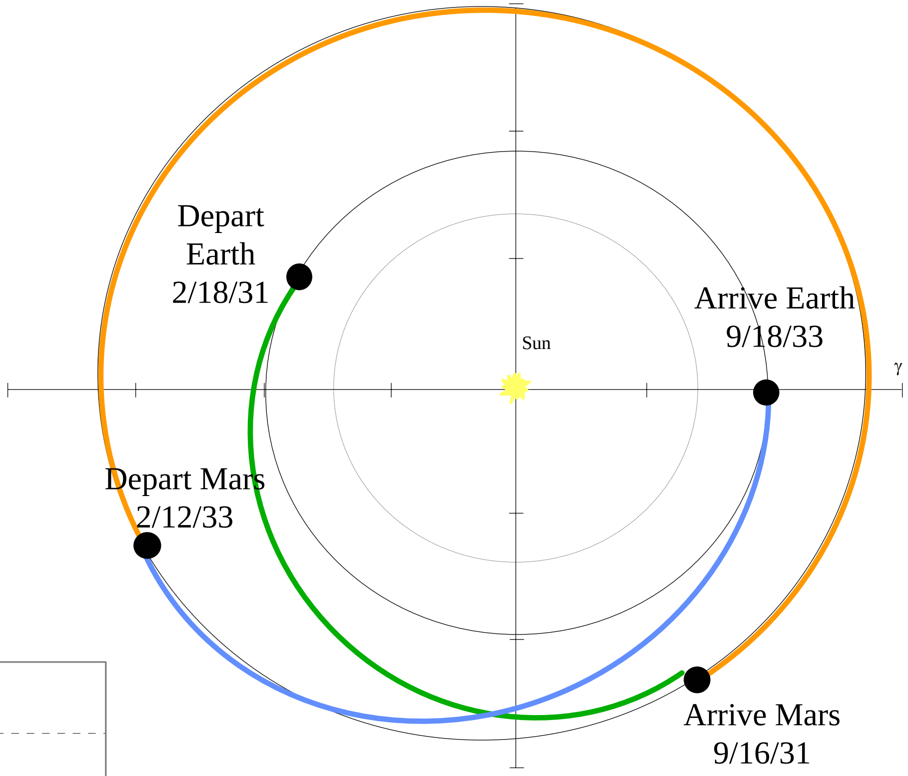
Architecture Elements

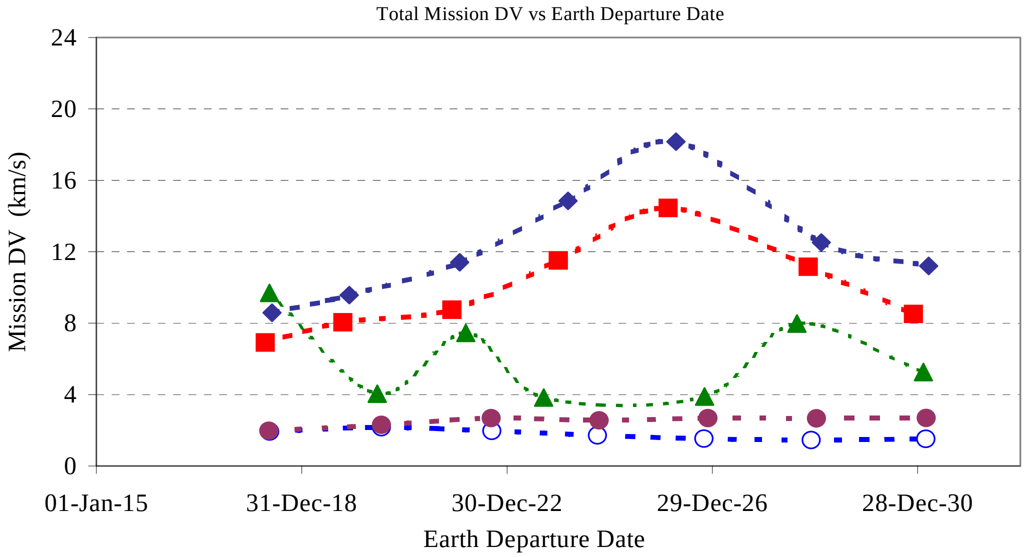
x 1 per mission	**Injection Stage**
x 1 per mission	**CEV + Power & Propulsion Module**
x 1 per mission	**Mars Lander**
	Artificial Gravity Mars Transit Vehicle (Reusable)

Notional Architecture

Example Long-Stay Missions

- **Typically referred to as *conjunction class* missions**
- **Characterized by**
  - Hohman transfers for both legs
  - All mission > 1 Au
  - Long-surface mission and total mission durations
  - Small variation in energy requirements across mission opportunities





Notional Architecture

Exploration Research Testbeds

Exploration Research Needs	Ground	ISS	Lunar	Mars Robotic
Integrated Mission Validation				
Vehicle, Flight, and Surface Ops Testbed	**s**	**s**	**P**	**s**
Science Operations Demonstration	**s**		**P**	**s**
Human Habitat/Lander Vehicle interior systems				
Regen Environmental Control and Life Support System	P	P	s	
Environmental Systems Tools and Techniques	P	s	s	P
(Air, water, toxicity)				
Human Health and Performance Research				
Micro G responses and related studies	P	P	s	
Exercise/countermeasures enhancements/validation	P	P	s	
Human factors implications for performance	P	P	s	
Autonomous Medical Health Care	P	P	s	
Surface/vehicle system threats (dust, microbes, radiation)	s	s	s	P
Sun and Galactic Radiation analysis/monitoring				
Radiation Dosimetry and shielding	P	P	s	s
Surface weather	s			P
In Situ Sustainability (Materials/Mechanical Sys Assessment)				
Low g manufacturing	P	P	s	s
Low g fluid and chemical research		P	s	

P = Primary   s = secondary

Notional Architectures

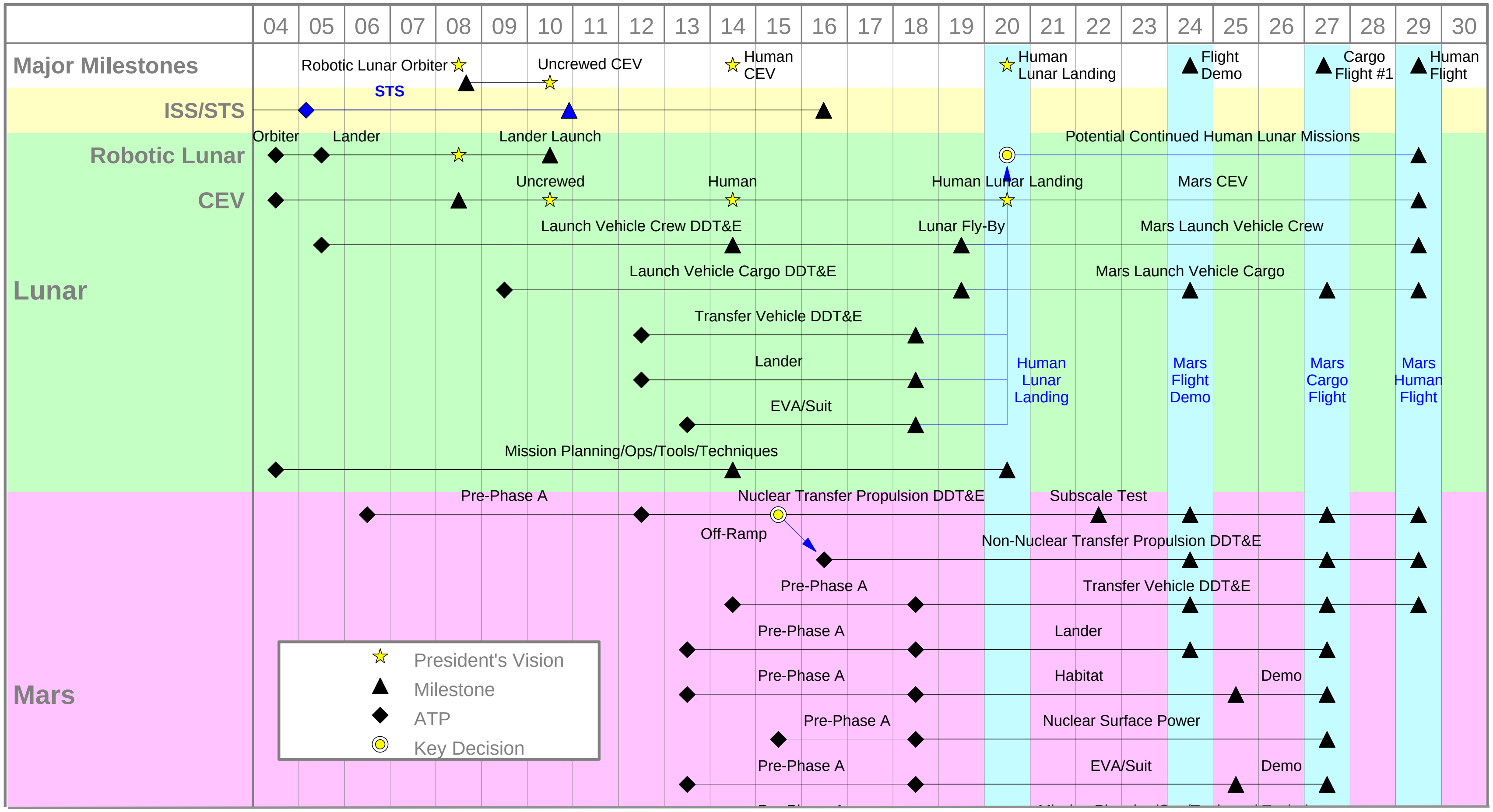
Critical Capabilities

- Launch Systems
  - **Cargo launch capability**
  - **Crew launch system**
- **In-Space Operations and Assembly**
  - Automated Rendezvous and Docking
  - On-orbit assembly
- **In-Space Transportation**
  - Aeroassist
  - Electric propulsion
  - Nuclear Propulsion
  - High-efficiency chemical propulsion
  - Long-Term Propellant storage and handling
- Planetary Operations
  - Entry / Descent / Landing
    - Aero Entry
    - Precision landing
- **Planetary Operations continued**
  - Surface Operations
    - Airlock / Dust Mitigation
    - Habitat / Laboratory
    - Mobility
    - EVA Suits
    - Subsurface Access / Sample Acquisition
    - Science Instrumentation
    - Resource Extraction, Utilization
  - Ascent Systems
- **Earth Return**
  - Entry system
  - Planetary protection
- **Cross-Cutting**
  - **Human Health and Performance**
  - Space and Surface
    - **Nuclear Power**
  - Self-sufficient Operations
  - Communications Infrastructure
  - Advanced Life Support

Highlighted items part of time-critical capability decisions

Notional Architecture

Strawman Timeline

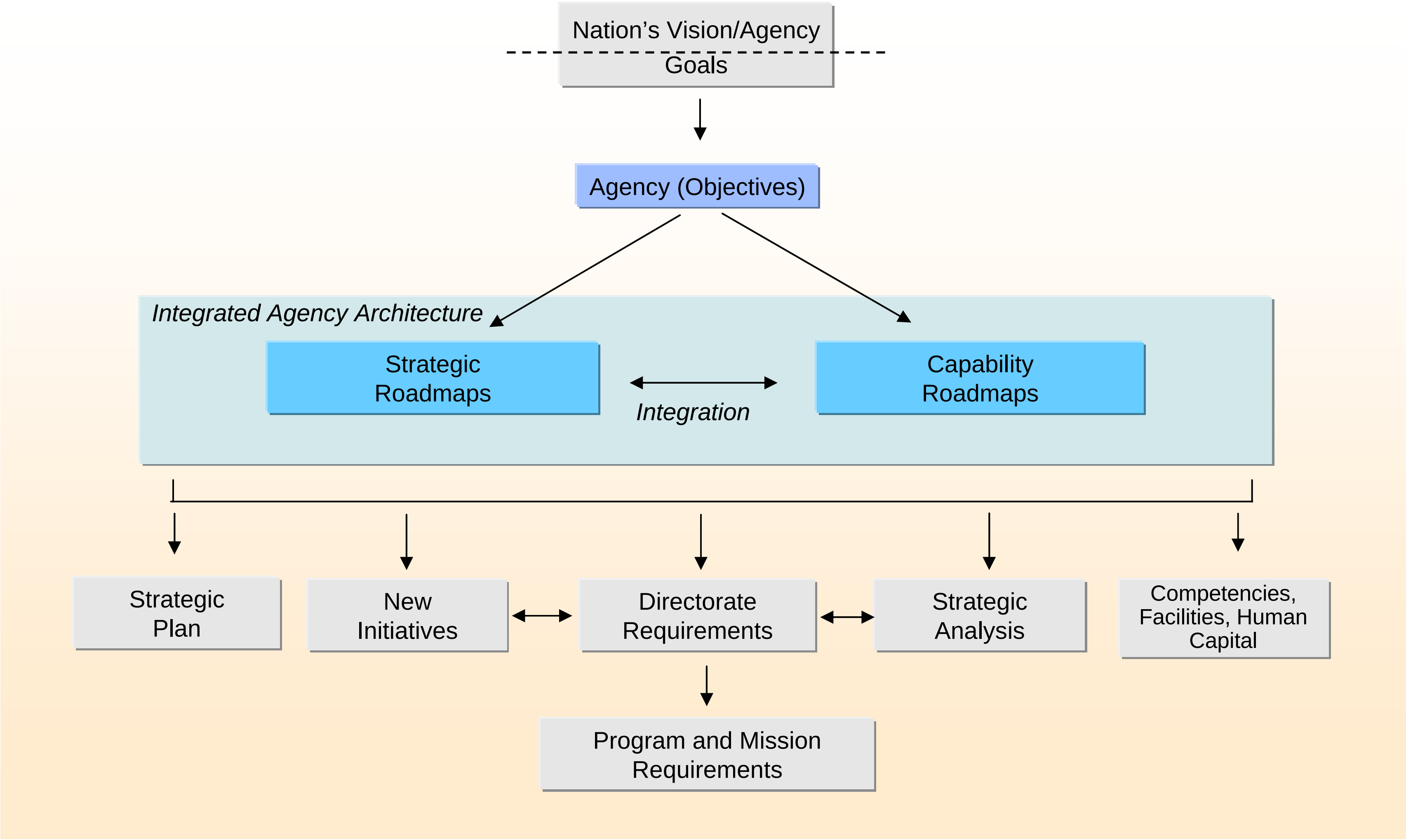


Near Term Decisions and Forward Work

- Earth to Orbit (ETO) Transportation
  - Understand the options for Shuttle heritage hardware for heavy lift and/or crewed launch systems
- Moon as a Testbed
  - Identify system, subsystem, and operational capabilities we need to test on the Moon to enable Mars and beyond
- Nuclear Investment Strategy
  - Identify the right level of commonality between robotic and human propulsion and between propulsion and surface power
- Management Strategy
  - Define the management and SE&I strategy needed to ensure product development and integration across the Enterprises
- Integrated Human-Robotic Approach
  - Identify robotic program objectives to acquire the environmental data and demonstrate key technologies to inform mission and system designers
- Exploration-Related Budget
  - Develop tools to assess cost and risk over a broad range of exploration architectural options
- Human Health & Performance
  - Develop human health and performance criteria in order to affect design of human-rated spacecraft and mission design
- Human Capital Strategy
  - Strategically plan for workforce and facility needs over the next few decades

Advanced Planning and Integration Office

Product Hierarchy and Requirements Flow



Nation's Vision/Agency Goals

Agency (Objectives)

Integrated Agency Architecture

Strategic Roadmaps

Integration

Capability Roadmaps

Strategic Plan

New Initiatives

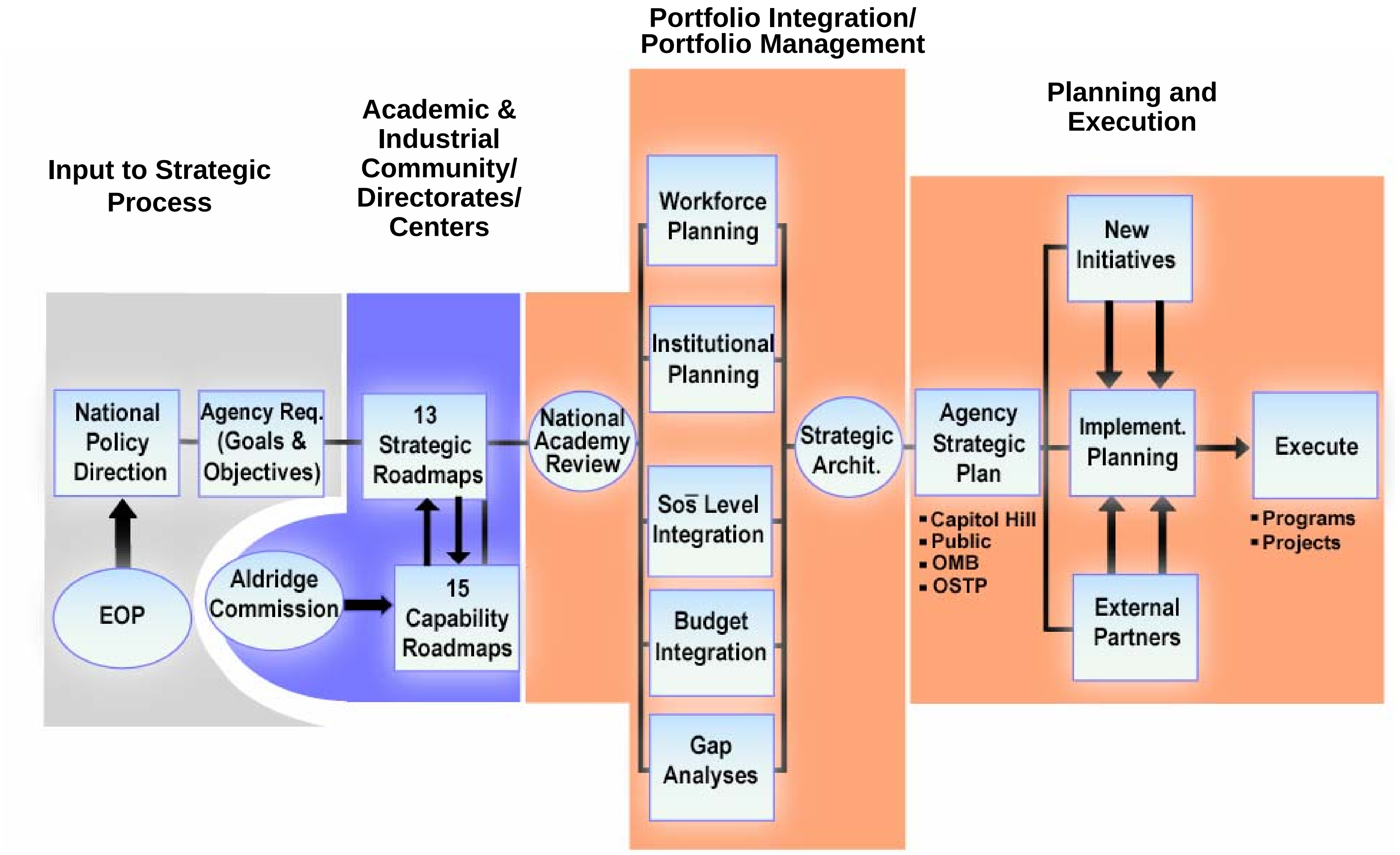
Directorate Requirements

Strategic Analysis

Competencies, Facilities, Human Capital

Program and Mission Requirements

Strategic Planning Framework



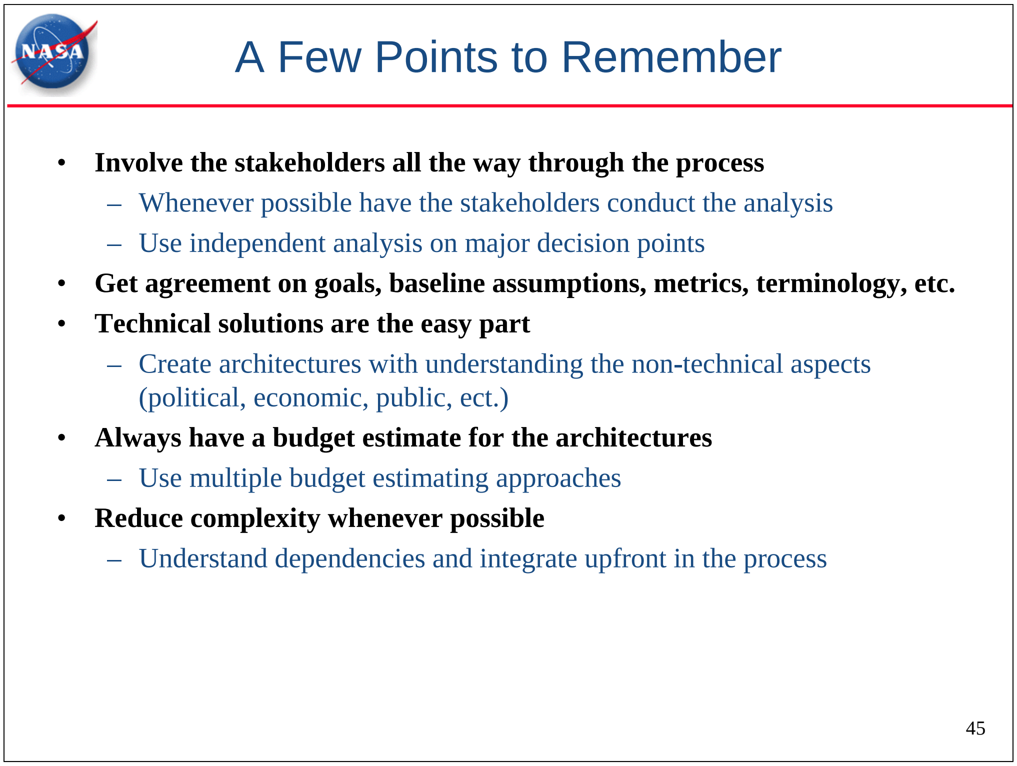
Directorates

Directorates

Advanced Planning and Integration Office

Roadmapping

- **Strategic Roadmap – A coordinated and comprehensive longitudinal strategy, with key decision points identified, that provides a foundation for investment decisions and priorities.**
  - Robotic and human lunar expeditions
  - Sustained, long-term robotic and human exploration of Mars
  - Sustained program of Solar System exploration
  - Advanced telescope searches for Earth-like planets and habitable environments
  - Develop an exploration transportation systems
  - Complete assembly of the International Space Station and focus utilization
  - Safely transition from Space Shuttle to new exploration focused launch systems
  - Explore the origin, evolution, structure and destiny of the Universe
  - Determine the behavior of the dynamic Earth system effected by natural and human induced processes and understand the consequences for life on Earth and beyond
  - Explore the Sun-Earth system and understand the effects of the Sun on the Earth, the Solar System and the implications for human exploration.
  - Transform air transportation and enable the next generation of atmospheric vehicles
  - Educate students and public and expand national technical skills and capabilities
  - Utilization of nuclear systems in civilian space missions



A Few Points to Remember

- **Involve the stakeholders all the way through the process**
  - Whenever possible have the stakeholders conduct the analysis
  - Use independent analysis on major decision points
- **Get agreement on goals, baseline assumptions, metrics, terminology, etc.**
- **Technical solutions are the easy part**
  - Create architectures with understanding the non-technical aspects (political, economic, public, ect.)
- **Always have a budget estimate for the architectures**
  - Use multiple budget estimating approaches
- **Reduce complexity whenever possible**
  - Understand dependencies and integrate upfront in the process

•Start with destinations close to earth

•Build up capability in size and distance

•Identify science drivers for each step.

•Building Blocks: what you can do now to provide for the capability in the future

ONE STEPPING STONE AT A TIME.

Return the Space Shuttle to Flight

The Cassini Orbiter's imaging system will map Titan, Saturn's largest moon

Complete the International Space Station

Series of robotic precursor missions to Earth's moon

Launch of James Webb Space Telescope

Crew Exploration Vehicle Operational

Launch of nuclear powered Jupiter Icy Moons Orbiter (JIMO)

Humans arrive on Earth's Moon

Mars robotic tested missions

Humans arrive on surface of Mars

The voyage continues, one step at a time...