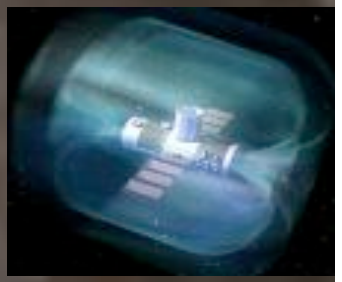
Exploration Requirements for Earth to Orbit

Doug Cooke

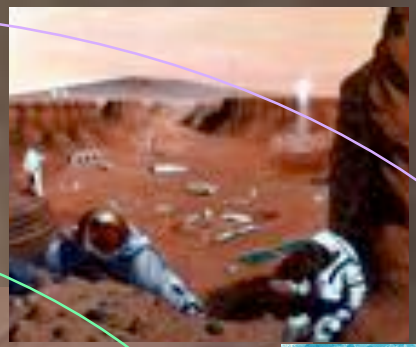
5/14/2002

Stepping Stones

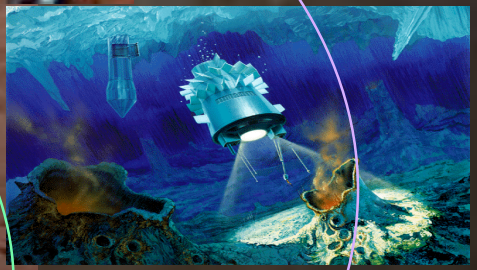


Go anywhere, anytime

Sustainable Planetary Surfaces

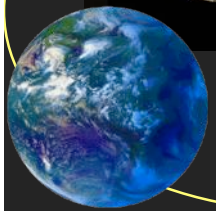


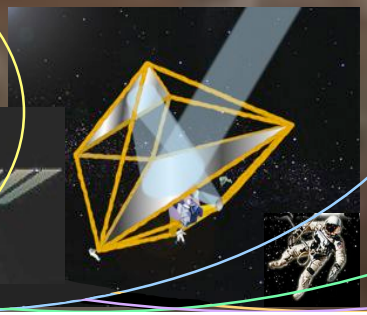
Accessible Planetary Surface



Earth's Neighborhood

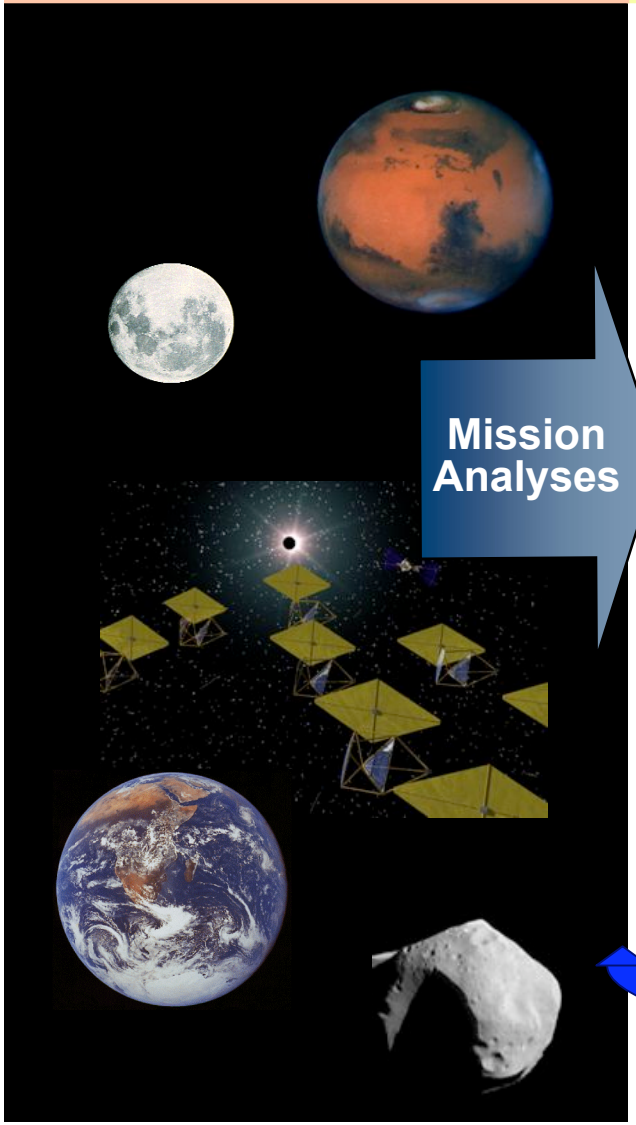
Earth and LEO





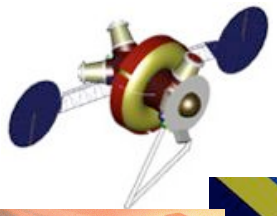
Core Capabilities & Technologies

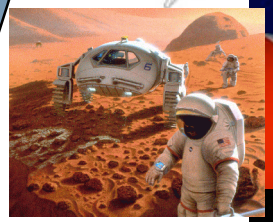
Potential Destinations from Science Objectives

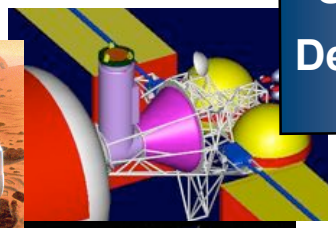


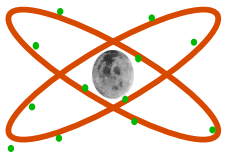
Mission Analyses

Common Capabilities









System Design(s)

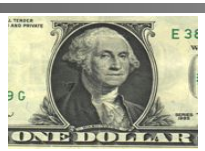
Technology Building Blocks

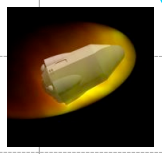
- Efficient In-Space
- Aeroassist
- Low-cost Engines
- Cryo Fluid
- Robust/Efficient
- Lightweight
- Radiation Research
- Zero/Low-g Research
- Regenerable Life
- Advanced Lightweight EVA

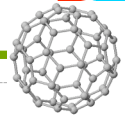
"Breakthrough" Technologies (Examples)

- Wireless Power
- Regenerative
- Revolutionary ETO Rockets
- Innovative Mission Concepts

The Value of Technology Investments
Mars Mission Example







Cumulative Mass Savings (Per Cent)

100
90
80
70
60
50
40
30
20
10
0

All Propulsive, Chemical

+Aerocapture (50%)

+Advanced Propulsion (EP or Nuclear) (46%)

+Closed Loop Life Support (19%)

+ Advanced Materials (14%)

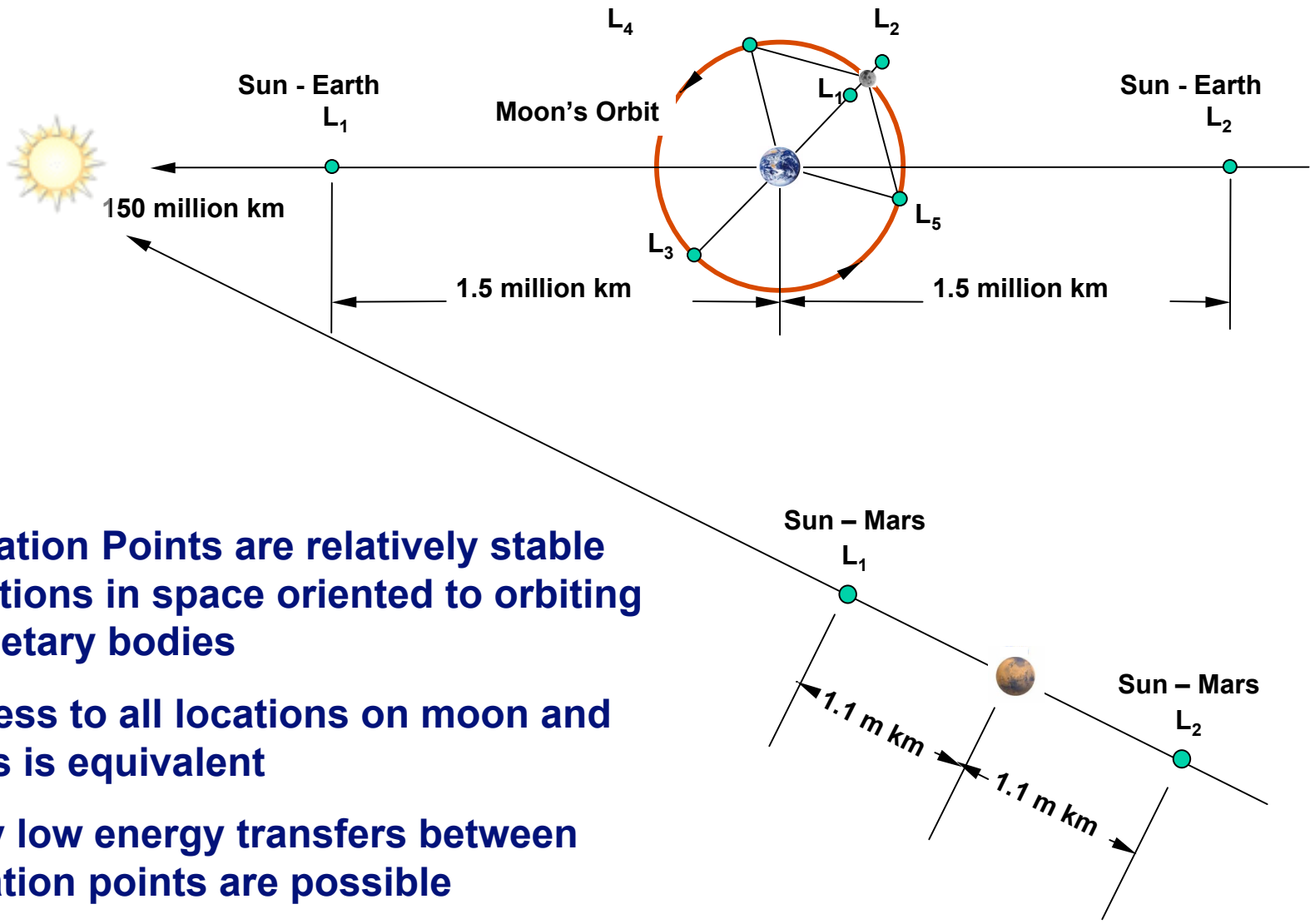
+ Maintenance & Spares (21%)

+Advanced Avionics (11%)

Today's Technology

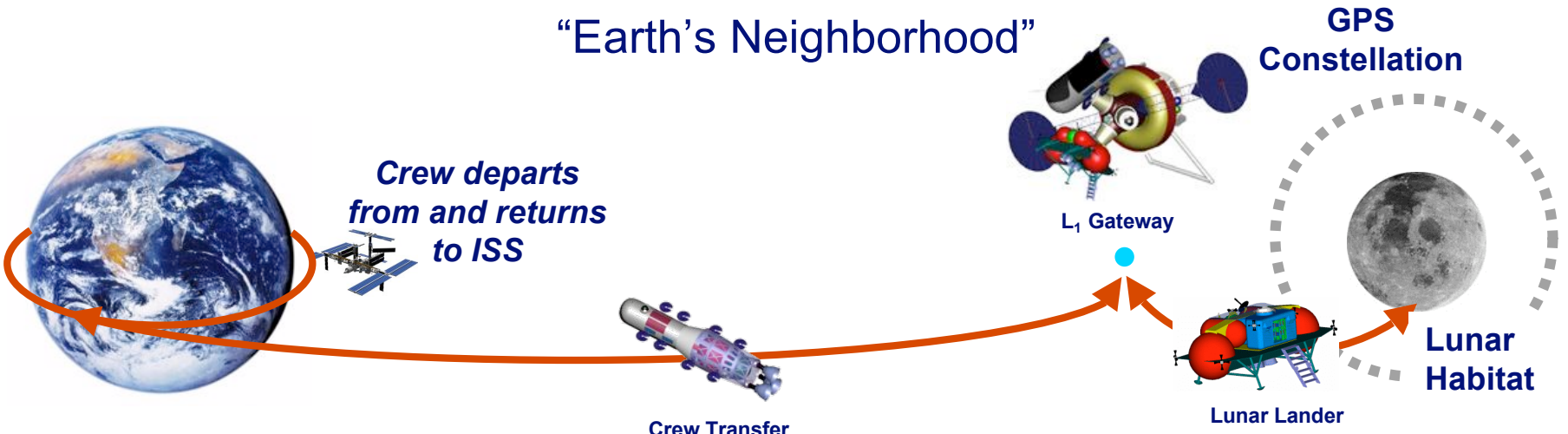
2/12/01

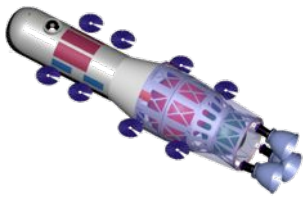
Libration Points and New Ideas



- 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

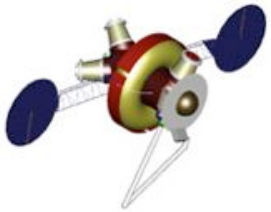
Gateway Architecture





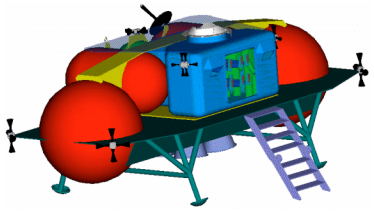
Crew Transfer Vehicle

- Transports crew between ISS and Gateway
- Nominal aerocapture to ISS, or direct Earth return contingency capability



L_1 Gateway

- "Gateway" to the Lunar surface
- Outpost for staging missions to Moon, Mars and telescope construction
- Crew safe haven



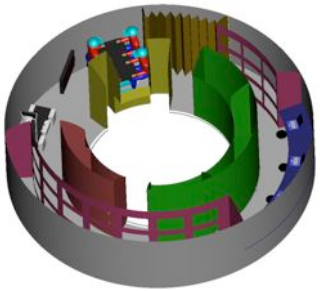
Lunar Lander

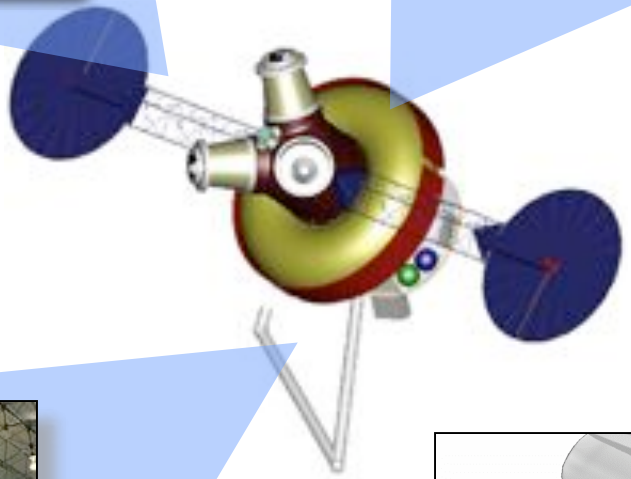
- Transports crew between Gateway and Lunar Surface
- 9 day mission (3 days on Lunar surface)

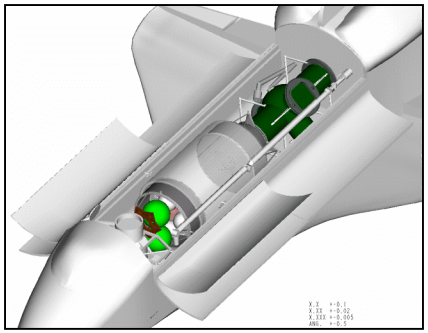
Lunar Habitat

- 30-day surface habitat placed at Lunar South Pole
- Enables extended-duration surface exploration and ops studies

Lunar L_1 "Gateway"





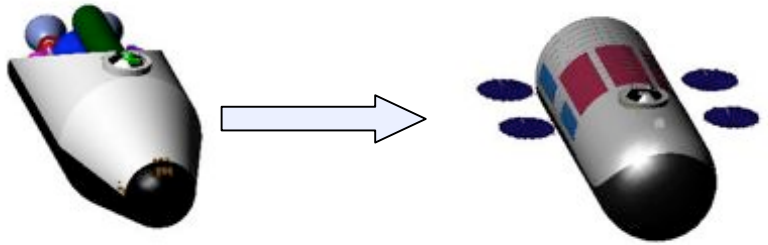


Key Attributes

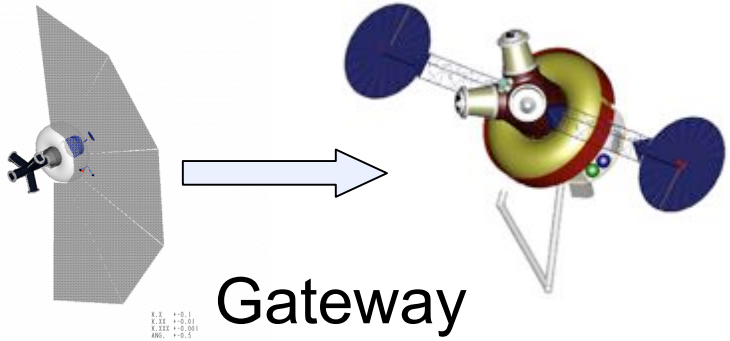
- **Earth-Sun Telescope assembly and servicing**
- **Gateway serves as "stepping stone" - opportunity to test technology and operational concepts**
- **Architecture can be bought "by the yard" - increasing capabilities and operational experience**
- **Employs existing and modest augmentation of existing launch vehicles**
- **Common architecture elements for all Earth's Neighborhood missions**
- **Potential for repairing outbound planetary spacecraft**

Earth's Neighborhood

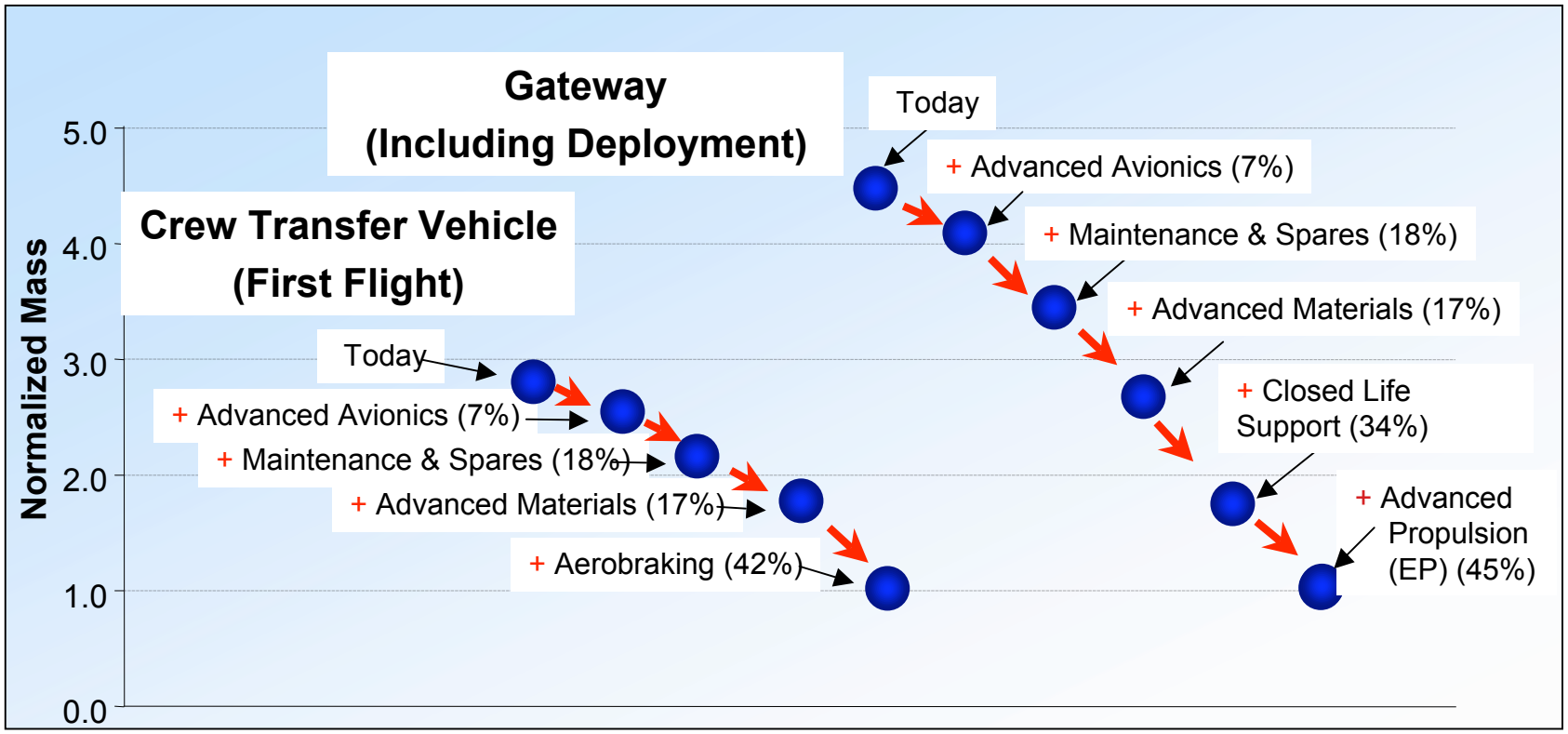
Evolution in Vehicle Designs



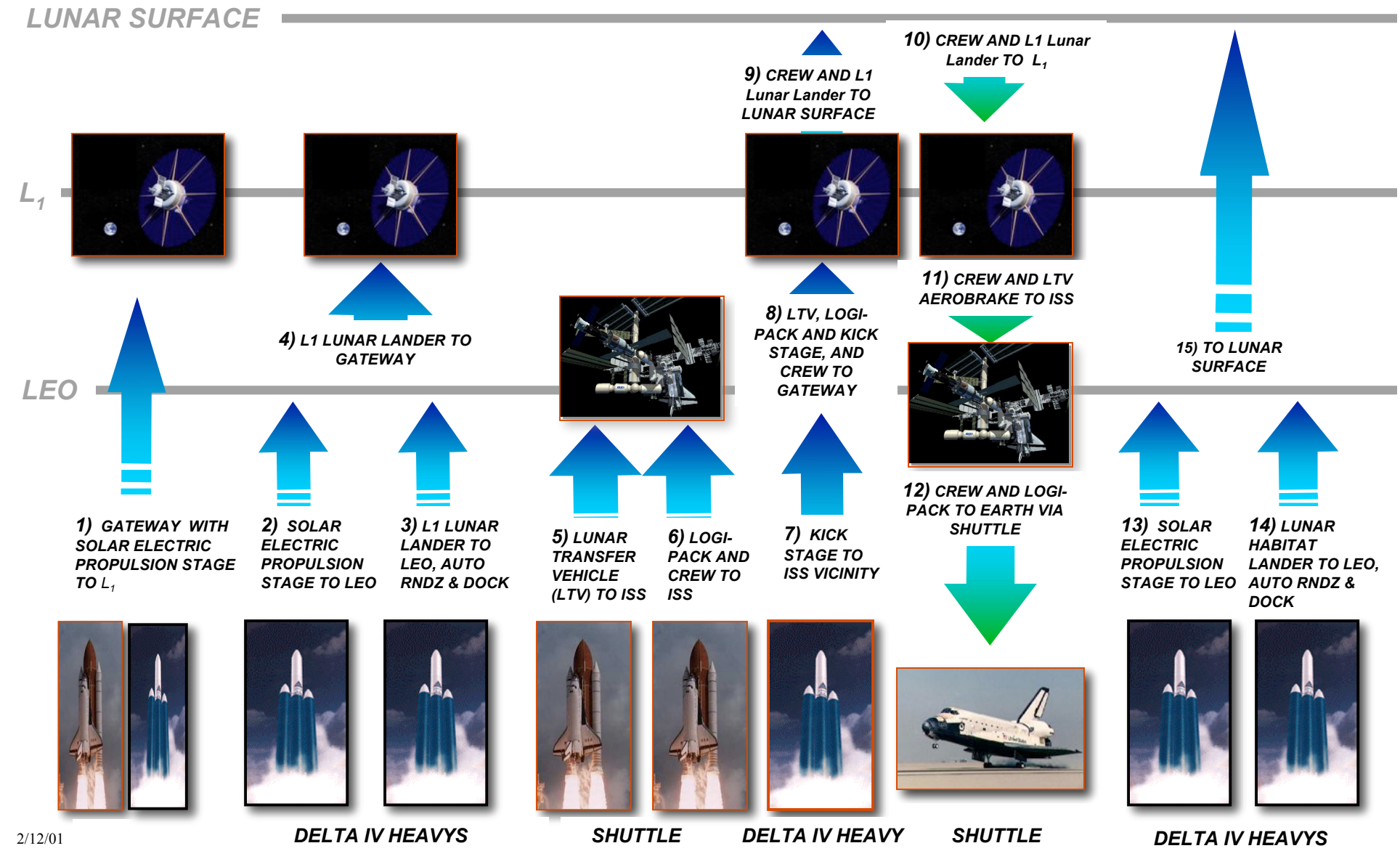
Crew Transfer Vehicle



Gateway

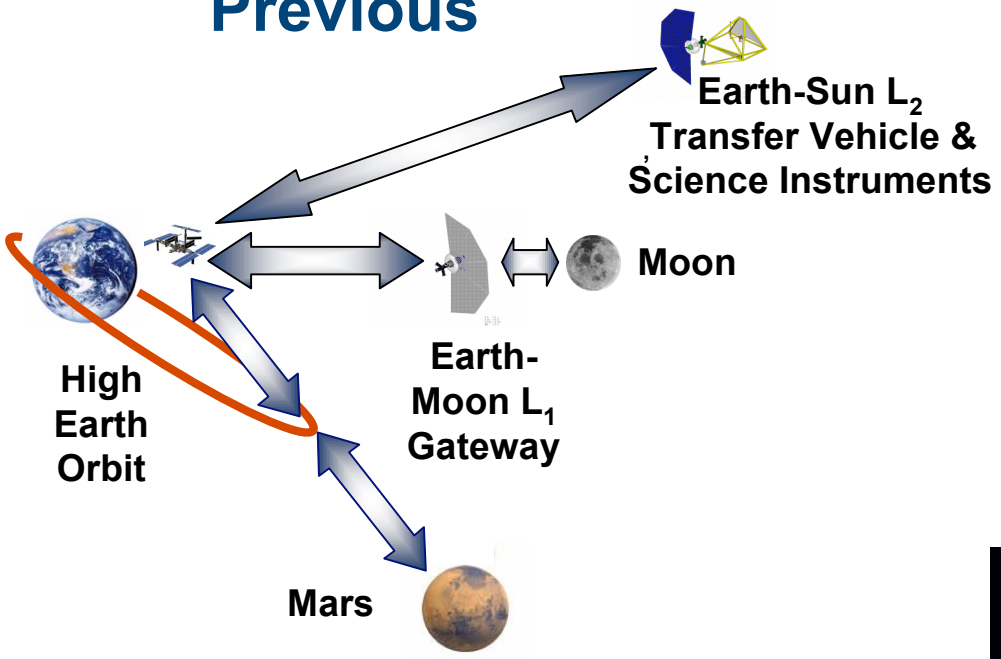


Mission Architecture Summary

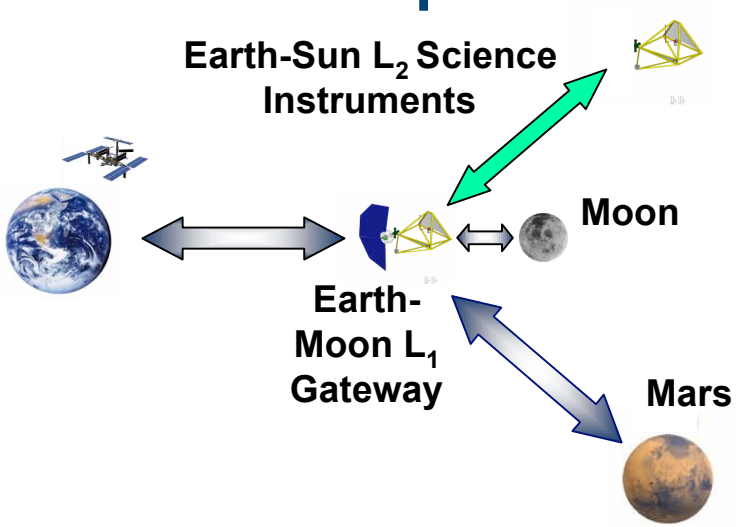


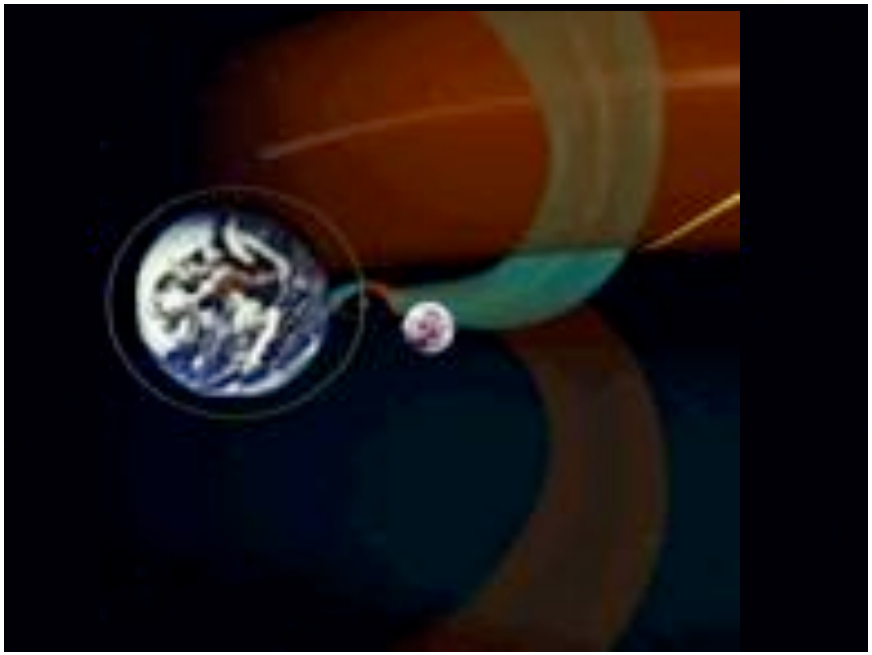
Simplifying Exploration Infrastructure

Previous



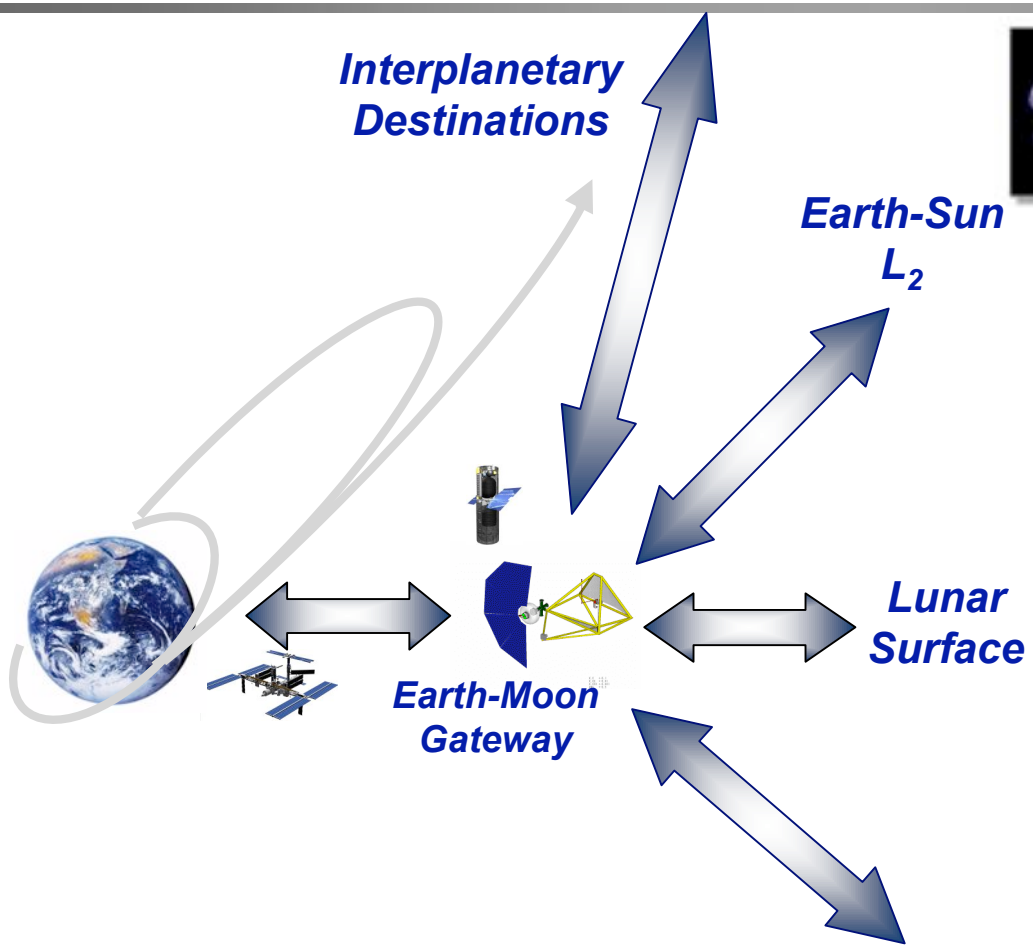
Simplified





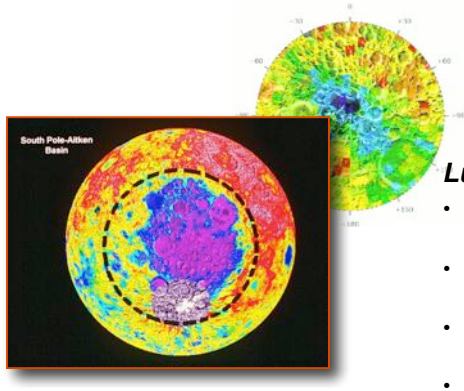
- Space Super Highways are corridors through the Solar System that balance the gravitational forces of the Sun and the Planets.
- Vehicles require minimal thrust and mass to move from one Libration point to another
- Earth System to Mars System transfers have the potential to transfer cargo at significant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

Potential "Earth's Neighborhood" Destinations



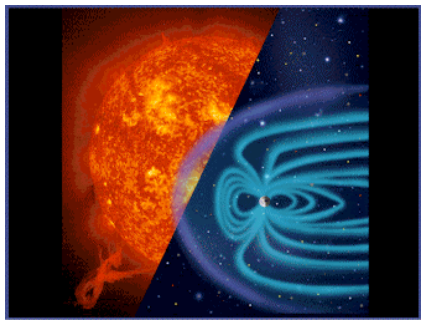
Construct, Deploy, and Service Advanced Astronomical Instruments

- Determine Physical Characteristics of Planetary Systems of other Stars
- Search for Worlds that Could or Do Harbor Life



Lunar Science

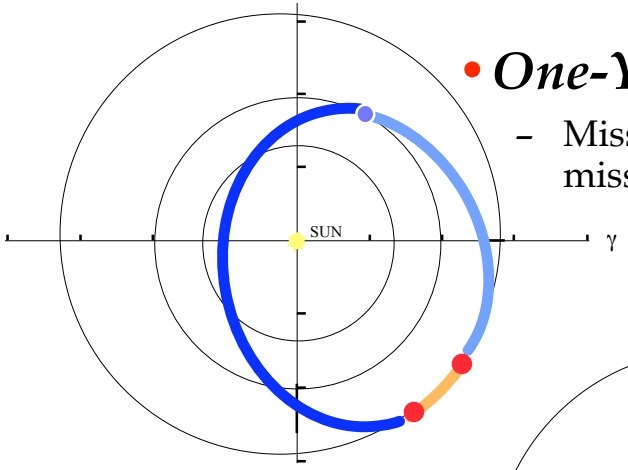
- Establish Impact History in Inner Solar System
- Determine Composition of Lunar Mantle
- Insight into Past and Current Solar Activity
- Poles - History of Volatiles in Solar System



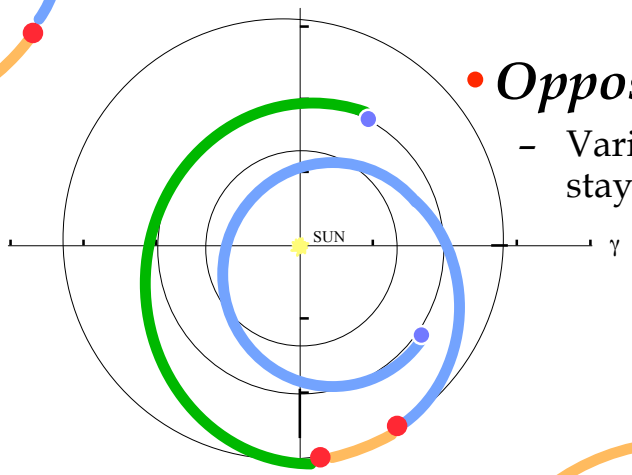
Construct and Deploy Solar Sentinels

- Understand Origins of Solar Variability
- Understand Effects on Solar Atmosphere and Heliosphere
- Understand Space Environment of Earth and Other Planets
- Improve Space Weather Forecasting

Trajectory Options Under Consideration

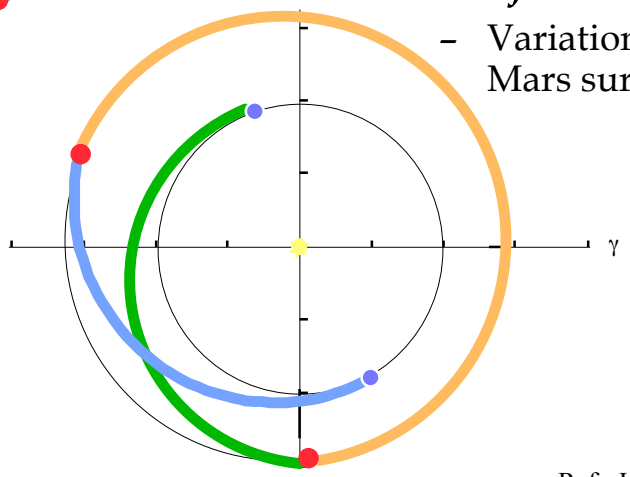


- **One-Year Mission**
  - Missions with short Mars surface stays with total mission duration of one year or less



- **Opposition Class Mission**
  - Variations of missions with short Mars surface stays and may include Venus swing-by

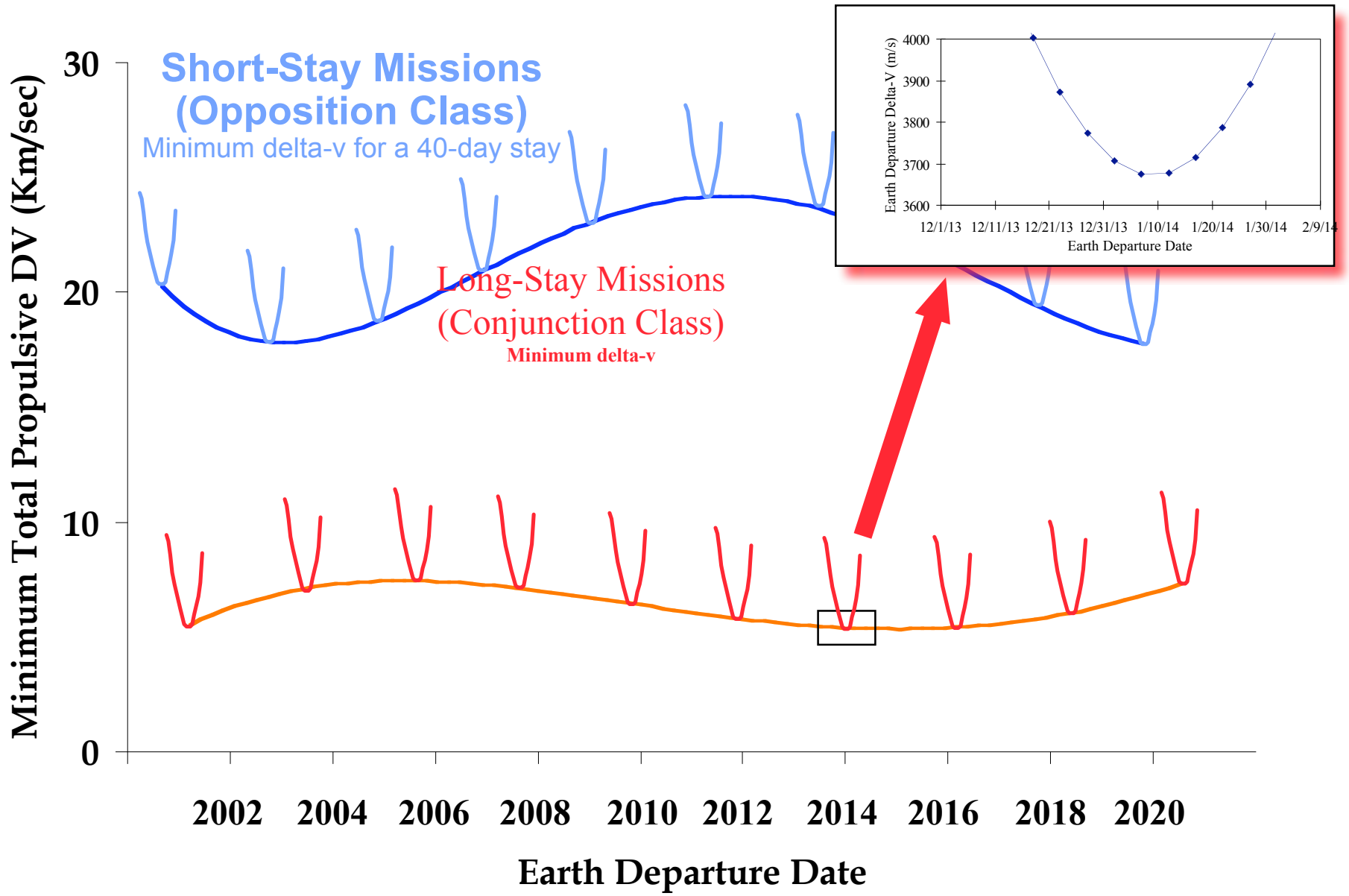
- **Conjunction Class Mission**
  - Variations of missions with long Mars surface stays.



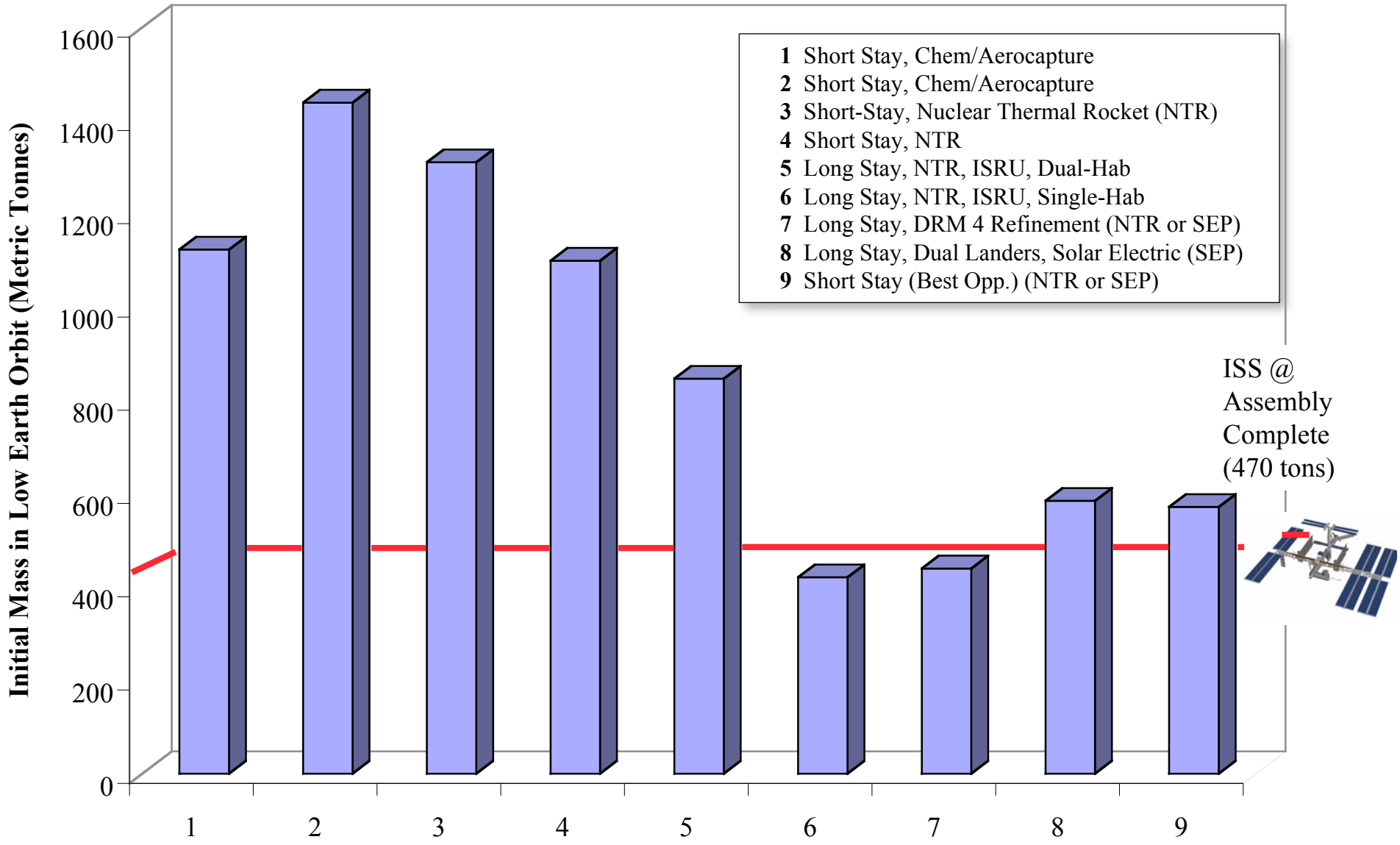
Outbound
Surface Stay
Inbound

Ref. Johnson Space Center

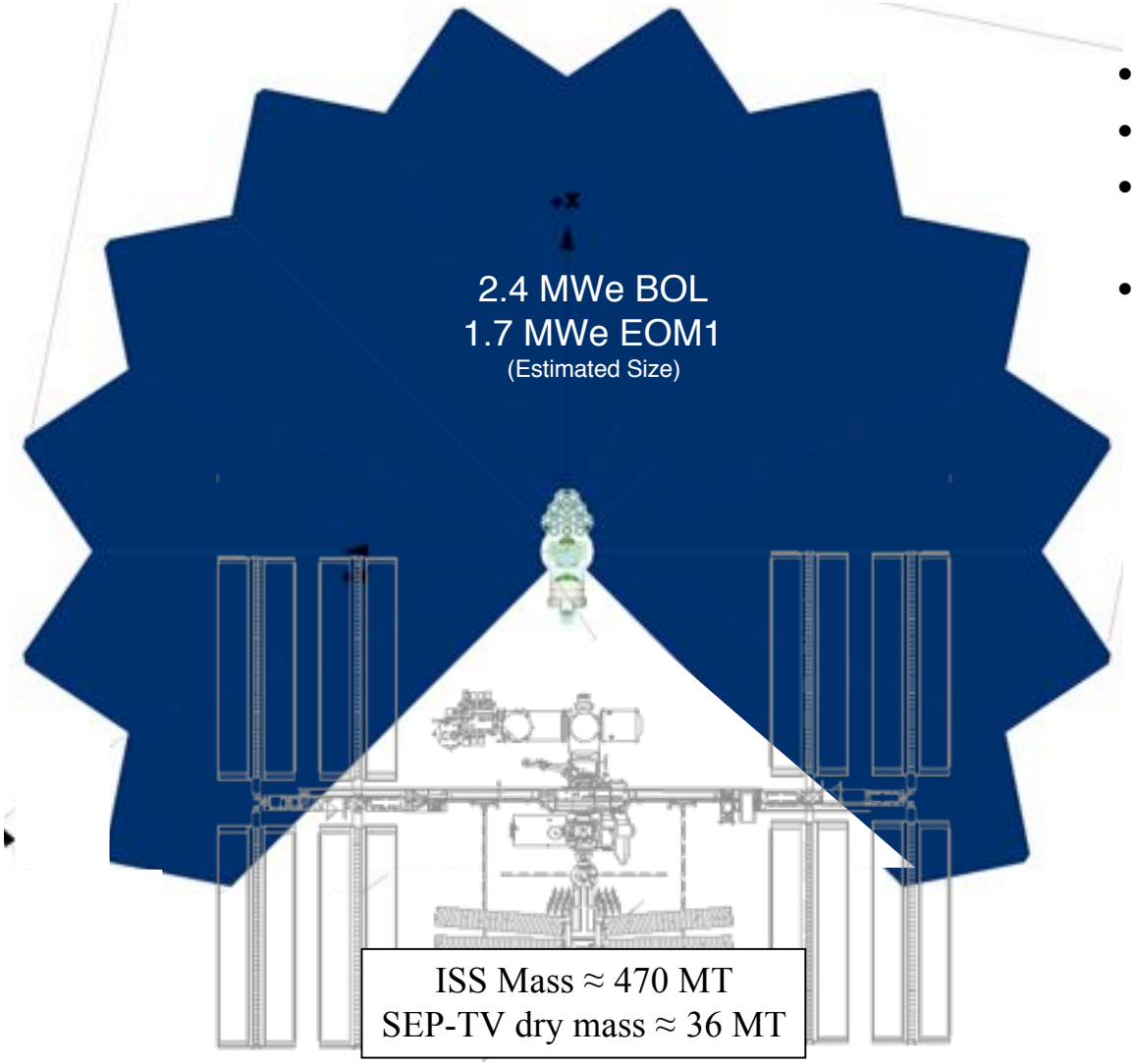
Round-Trip Mars Mission Energy (Delta-V) Variations



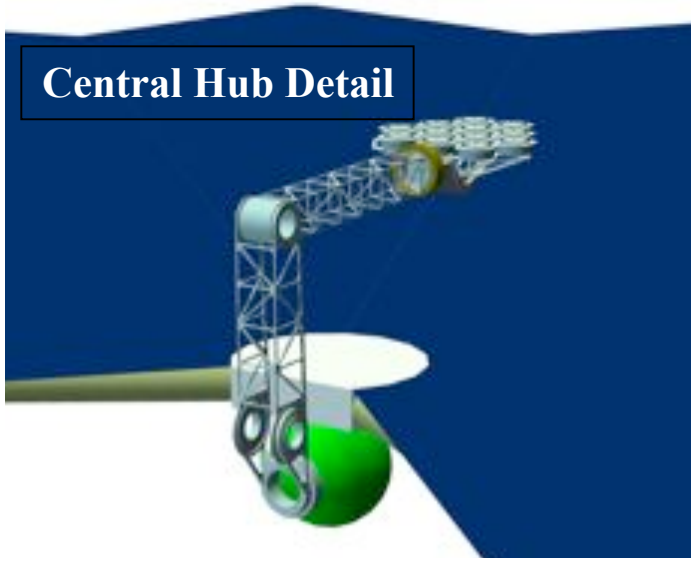
Mars Architecture Mass Comparison



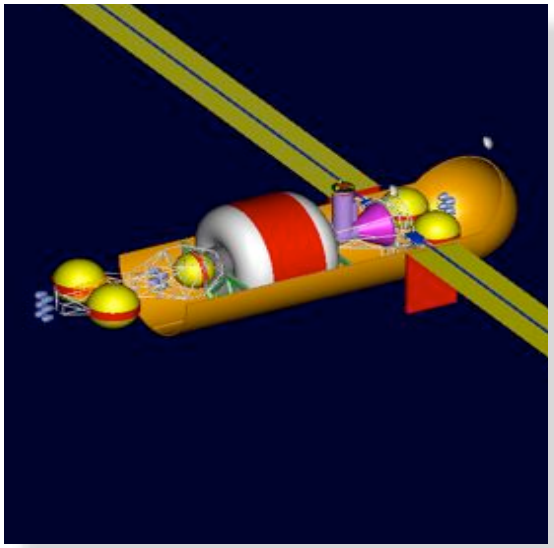
Solar Electric Propulsion Concept



- **Array sized to provide 1700 kW_e throughout first mission**
- **14700 m^2 $CuInS_2$ array area**
- **171 m span (wingtip-wingtip)**
- **17 x 100 kW_e Hall Thruster Propulsion**
- **Articulated boom thruster**

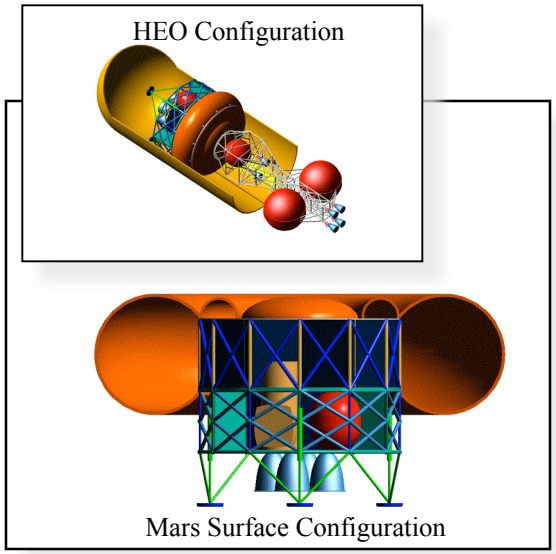


Mars Mission Vehicle Concepts



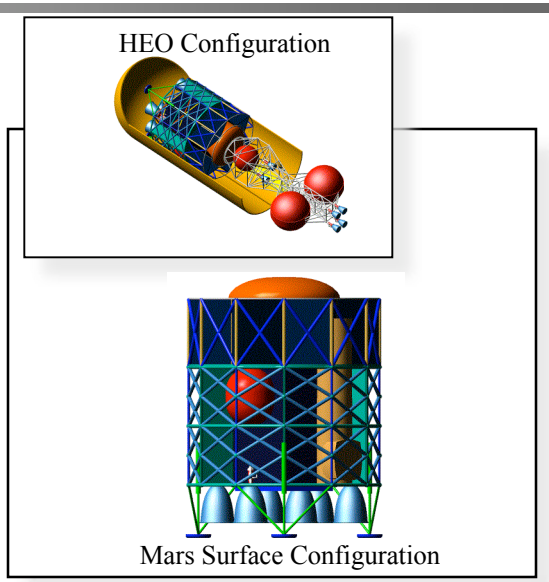
Mars Transit Vehicle

- Supports mission crew of six for up to 200-day transits to and from Mars
- Return propulsion stage integrated with transit system
- Provides return-to Earth abort capability for up to 30 hours post-TMI
- Total Vehicle Mass in High-Earth Orbit = 188 mt



Mars Surface Habitat

- Vehicle supports mission crew of six for up to 18 months on the surface of Mars
- Provides robust exploration and science capabilities
- Descent vehicle capable of landing 36,000 kg
- Total Vehicle Mass in High-Earth Orbit = 99 mt

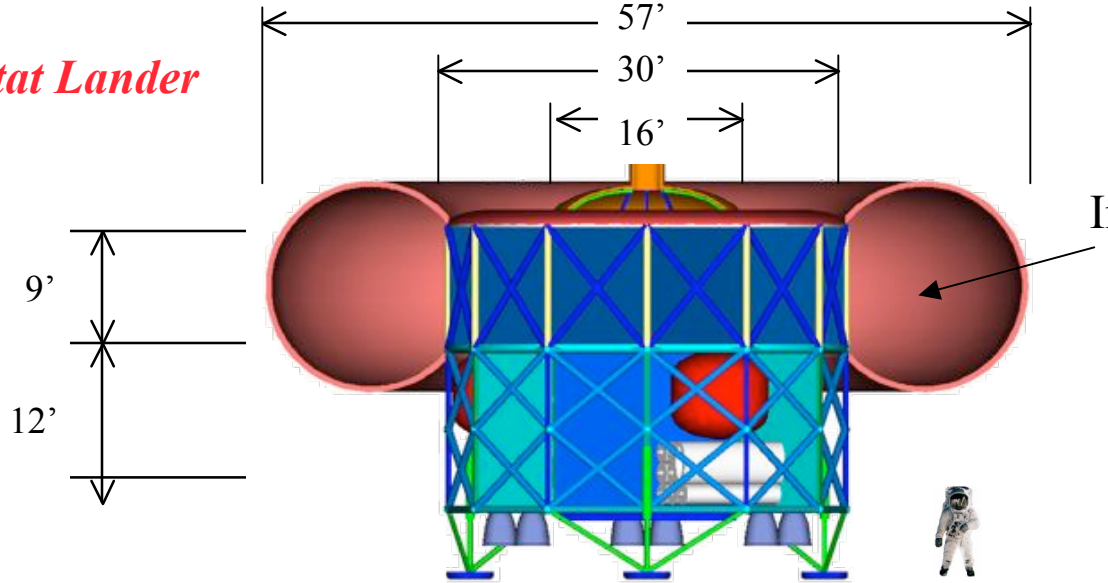


Descent/Ascent Vehicle

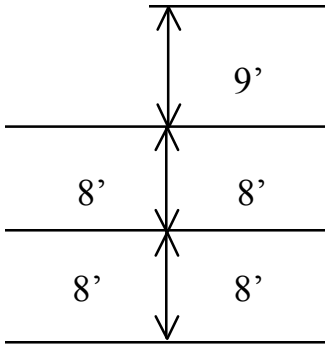
- Transports six crew from Mars orbit to the surface and back to orbit
- Provides contingency abort-to-orbit capability
- Supports six crew for 30-days
- Vehicle capable of utilizing locally produced propellants
- Total Vehicle Mass in High-Earth Orbit = 103 mt

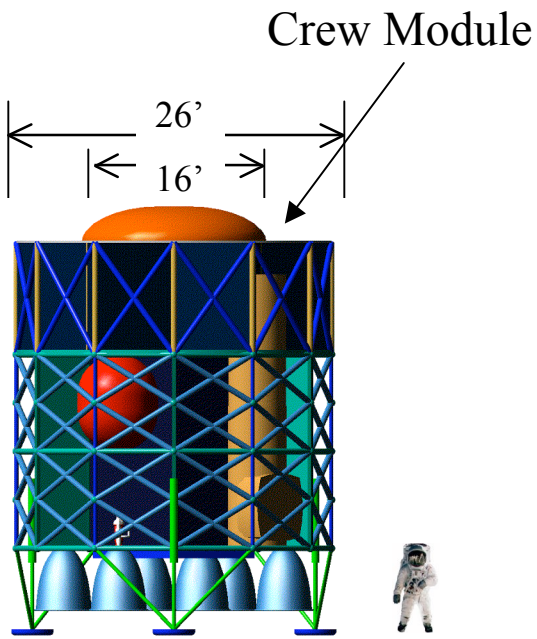
Lander Dimensions

Habitat Lander

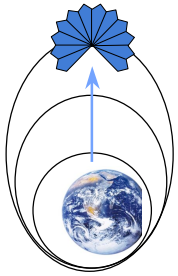


Descent / Ascent Vehicle



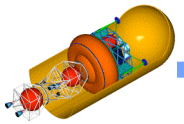


Mars Mission Overview

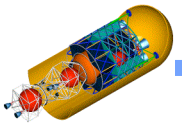


Habitat Lander and Ascent/Descent Vehicles delivered to Low Earth Orbit with Magnum. Solar Electric Propulsion stage spirals cargo to High Earth Orbit. Chemical injection used at perigee. SEP spirals back to LEO for reuse.

Surface Habitat and exploration gear aerocaptures into Mars orbit

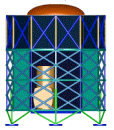


Ascent/Descent Vehicle aerocaptures and remains in Mars orbit for the crew

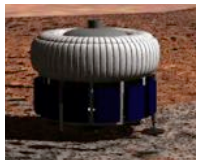


Crew rendezvous with Descent/Ascent Vehicle in Mars Orbit then lands in vicinity of Habitat Lander

Surface Habitat lands and performs initial setup and checkout - Initial outpost established



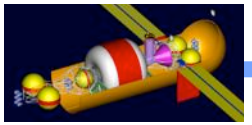
30 days provided to satisfy "long-stay" criteria.



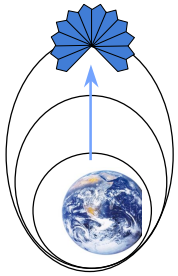
Mars Surface

Crew ascends and rendezvous with waiting Transit Habitat

Habitat remains in Mars orbit

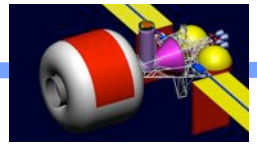


Crew travels to Mars in "fast transit" 180-day transfer. Aerobrakes into Mars orbit



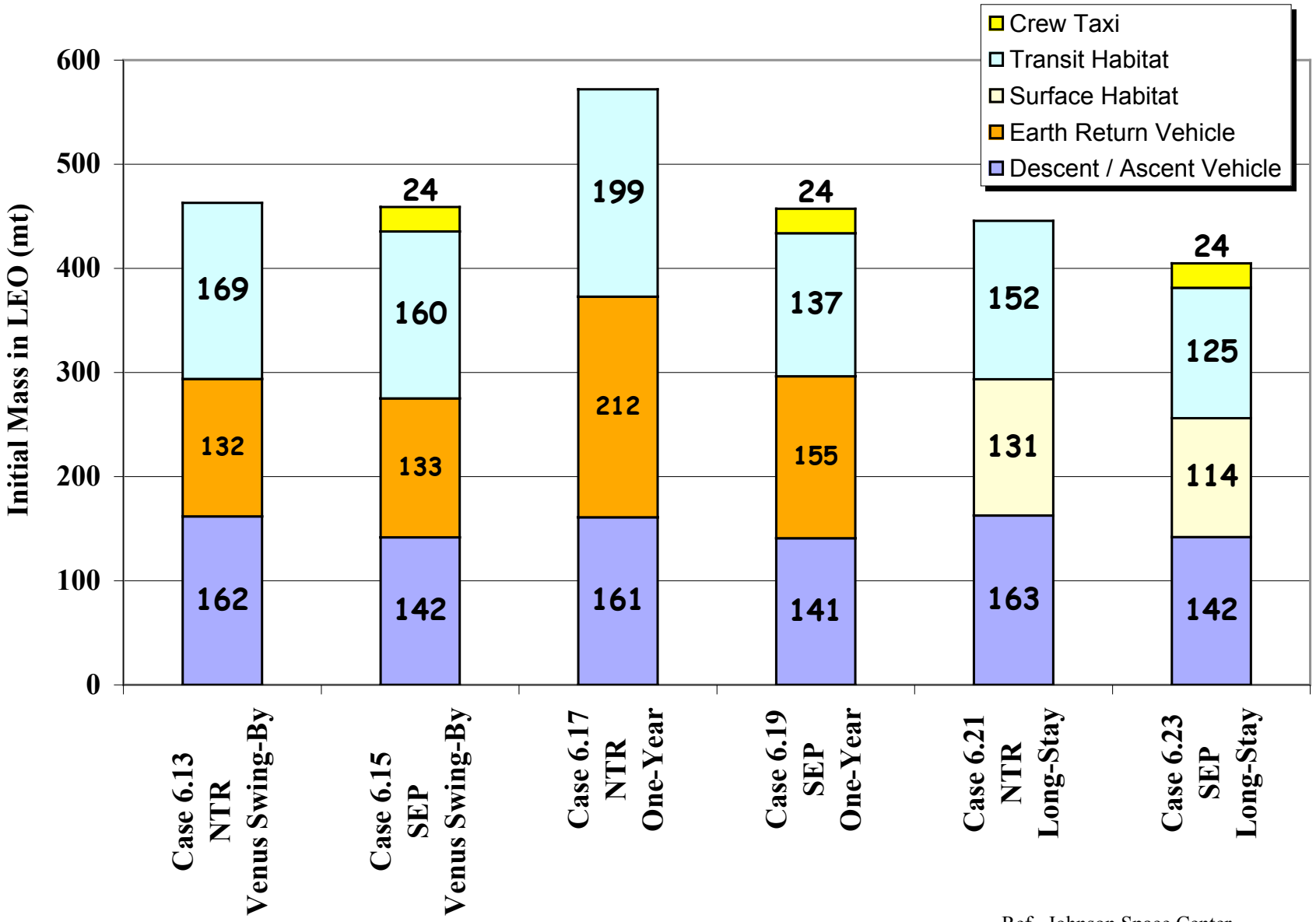
Transit Habitat vehicle delivered to LEO with Magnum. SEP spirals Transit Habitat to High Earth Orbit. Crew delivered to vehicle via crew taxi. SEP spirals back to LEO for reuse.

Earth Orbit



Crew returns to Earth on "fast transit" 180-day transfer. Direct entry at Earth

Mars Mid-term Case Study Set 2 Results



2/12/01

Ref. Johnson Space Center

Mission Sequence
High Earth Orbit Boost Phase

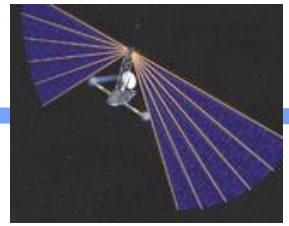
Bret Drake / EX

UNPILOTED VEHICLES

"Shuttle Class" 2
SEP launched to low Earth orbit

"Shuttle Class" 3
Descent/Ascent vehicle, aerobrake, and TMI stage launched LEO

"Shuttle Class" 4
Surface Habitat Lander, aerobrake, and TMI stage launched LEO



SEP vehicles boost Descent/Ascent and Surface Hab landers to High Earth Orbit

STS 4 / Taxi
Servicing mission in High Earth Orbit

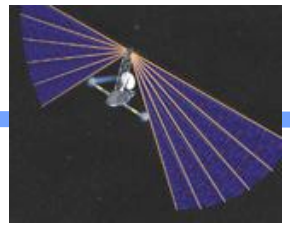
PILOTED VEHICLES

"Shuttle Class" 1
Transit Habitat launched to low Earth orbit

STS 1 & 2
Transit Habitat outfitting missions

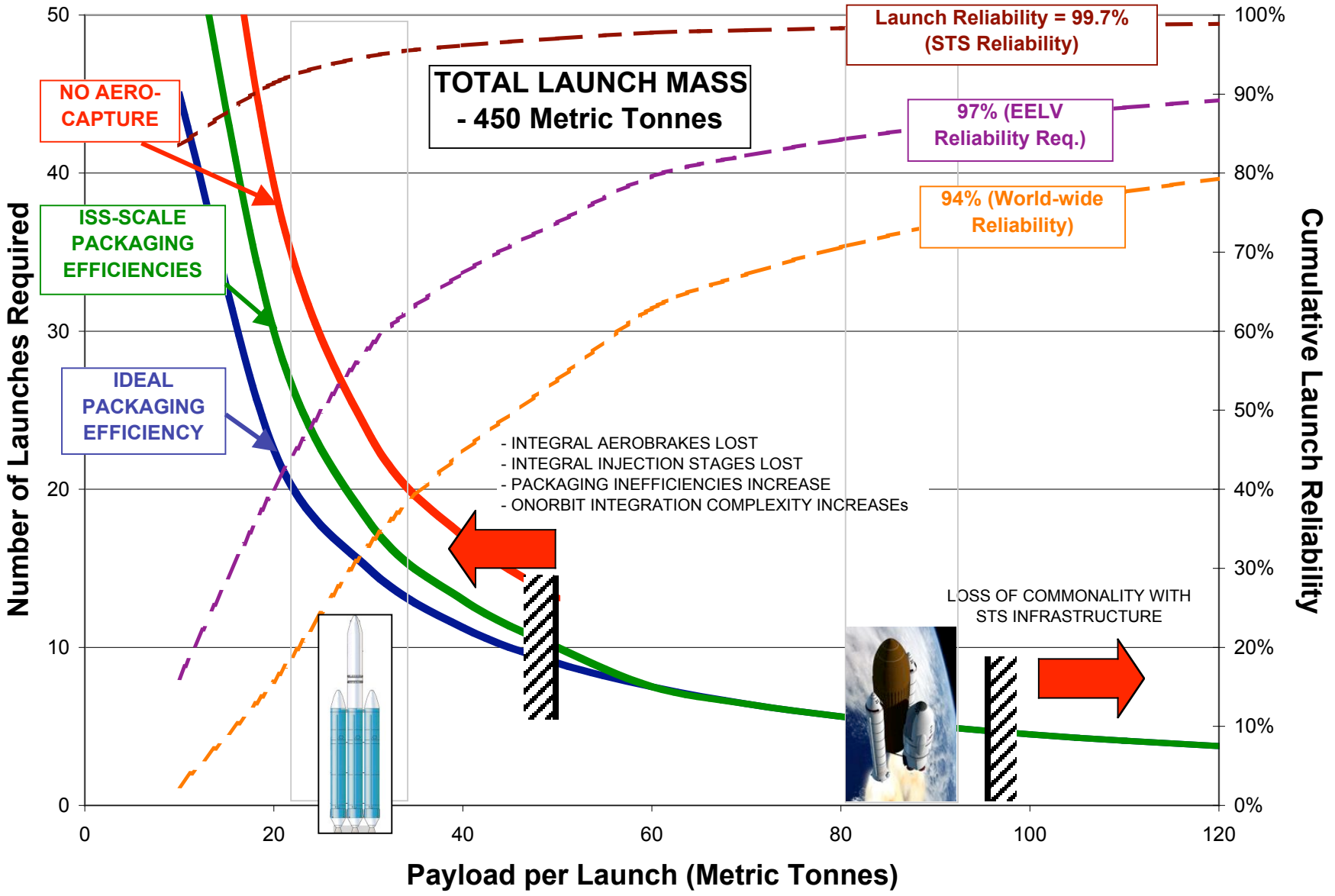
"Shuttle Class" 5
Transit Habitat SEP vehicle launched to low Earth orbit

"Shuttle Class" 6
Transit Habitat propulsion stages launched to low Earth orbit



SEP vehicle boosts Transit Habitat to High Earth Orbit

STS 3 / Taxi
Transit Habitat servicing mission in High Earth Orbit


TOTAL LAUNCH MASS
- 450 Metric Tonnes
Launch Reliability = 99.7%
(STS Reliability)
97% (EELV
Reliability Req.)
94% (World-wide
Reliability)
NO AERO-
CAPTURE
ISS-SCALE
PACKAGING
EFFICIENCIES
IDEAL
PACKAGING
EFFICIENCY
- INTEGRAL AEROBRAKES LOST
- INTEGRAL INJECTION STAGES LOST
- PACKAGING INEFFICIENCIES INCREASE
- ONORBIT INTEGRATION COMPLEXITY INCREASEs
LOSS OF COMMONALITY WITH
STS INFRASTRUCTURE
Number of Launches Required
Cumulative Launch Reliability
Payload per Launch (Metric Tonnes)
0
10
20
30
40
50
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
0
20
40
60
80
100
120

Effects of "Launch Package" Size

- Range of individual launch package masses have been assessed for exploration missions
- Package sizes in the range of current launch capabilities show significant disadvantages
  - Mass efficiency losses due to non-optimal packaging - ISS experience is ~70% utilization
  - Design inefficiencies for large volumes (prop tanks, habitat module)
    - Increase in interfaces
    - Excessive mass for bulkheads, docking mechanisms, plumbing
  - Increased reliance on on-orbit construction of flight-critical structures
    - Heat shields, aerobrakes
  - Reliability of launch vehicle would need to be extremely high for successful launch of all components
- Payloads consistent with STS-level GLOW launch vehicle could orbit 80-100 metric tons
  - Could relieve these concerns
  - Could have small impact to current launch infrastructure

Exploration Requirements

- Payload Mass- 80 to 100 metric tons (100 preferred)
- Delivery to 28.5 degree inclination, 407 km altitude
- Rendezvous with pre-deployed assets in Earth orbit
- Volume- 8m dia. X 30m length
- Reliability- 99.7% or better (Shuttle Equivalent)
- Goal- $1000 per pound
- Cargo launch Shroud= Mars entry heat shield

Summary

- NASA has conducted human Mars mission studies for more than 12 years
  - Variety of mission goals
  - Variety of mission durations
  - Variety of assumptions in technology employed
- Total initial mission mass in low earth orbit has varied from 400 to 1400 metric tons to send a crew to Mars
- Current estimated mass~ 450 metric tons
- Launch package sizes on the order of 80 to 100 metric tons allow for simplest interfaces between vehicle components