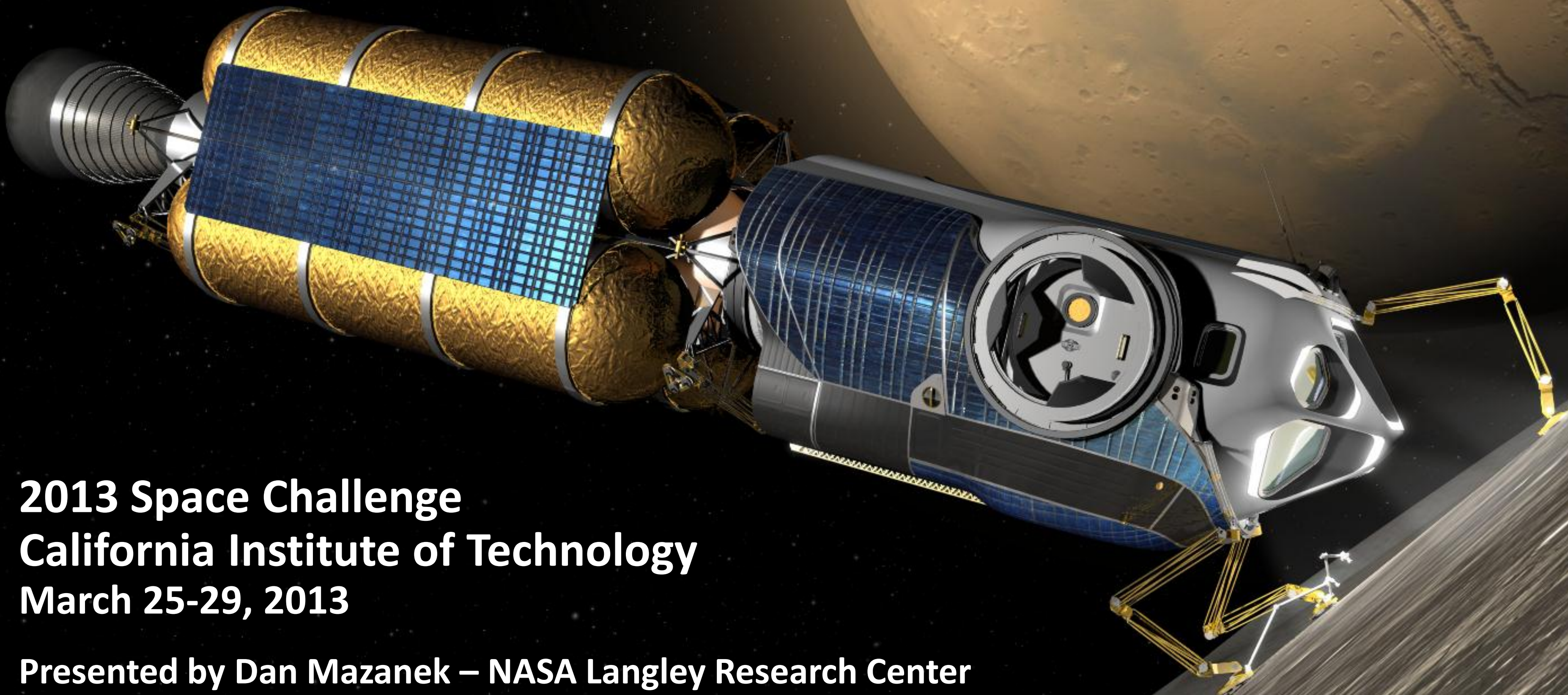
National Aeronautics and Space Administration

Considerations for Designing a Human Mission to the Martian Moons



2013 Space Challenge
California Institute of Technology
March 25-29, 2013

Presented by Dan Mazanek – NASA Langley Research Center

NASA Human Spaceflight Architecture Team (HAT) Primary Team Members:

Paul Abell (JSC), Jeff Antol (LaRC), Brent Barbee (GSFC), David Beaty (JPL), Deborah Bass (JPL), Julie Castillo-Rogez (JPL), David Coan (JSC), Tony Colaprete (ARC), Kevin Daugherty (LaRC), Bret Drake (JSC), Kevin Earle (LaRC), Lee Graham (JSC), Mike Hembree (JSC), Steve Hoffman (JSC), Sharon Jefferies (LaRC), Ruthan Lewis (GSFC), Mark Lupisella (GSFC), Dan Mazanek (LaRC – Study Lead) and David Reeves (LaRC)

One Man Musings on Ideas

"He who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine, receives light without darkening me.

That ideas should freely spread from one to another over the globe, for the moral and mutual instruction of man, and improvement of his condition, seems to have been peculiarly and benevolently designed by nature, when she made them, like fire, expansible over all space, without lessening their density in any point, and like the air in which we breathe, move, and have our physical being, incapable of confinement or exclusive appropriation."

– Thomas Jefferson
Third President of the United States

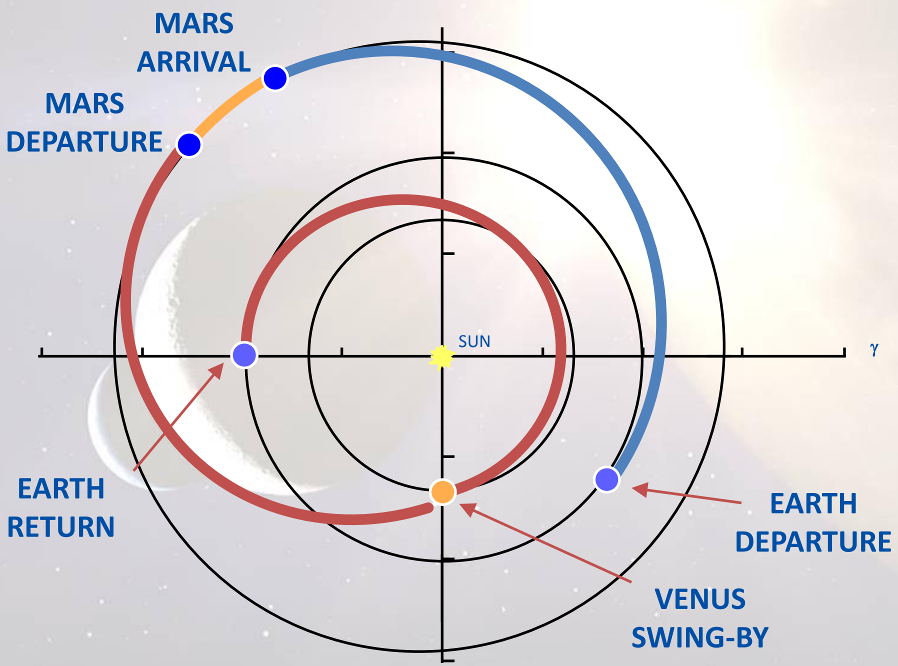
Overview of HAT Mars-Phobos-Deimos Study

- **Background:** In early 2012, members of the NASA Human Spaceflight Architecture Team (HAT) developed a preliminary Destination Mission Concept (DMC) for the Martian moons and provided inputs for potential establishment of a future Design Reference Mission (DRM).
- **Goal:** Determine whether an opposition-class mission (short-stay of ~30-90 days in the Mars system) provides sufficient time to meet a worthwhile number of the science and exploration objectives at Phobos, at Deimos, and in Mars orbit, or if a conjunction-class mission (long-stay of ~450-540 days in the Mars system) is required.
- **Context:** Mars-Phobos-Deimos (MPD) conceptual mission was envisioned as a follow-on to a human mission to a near-Earth asteroid (NEA) and as a possible preliminary step prior to a human landing on Mars.

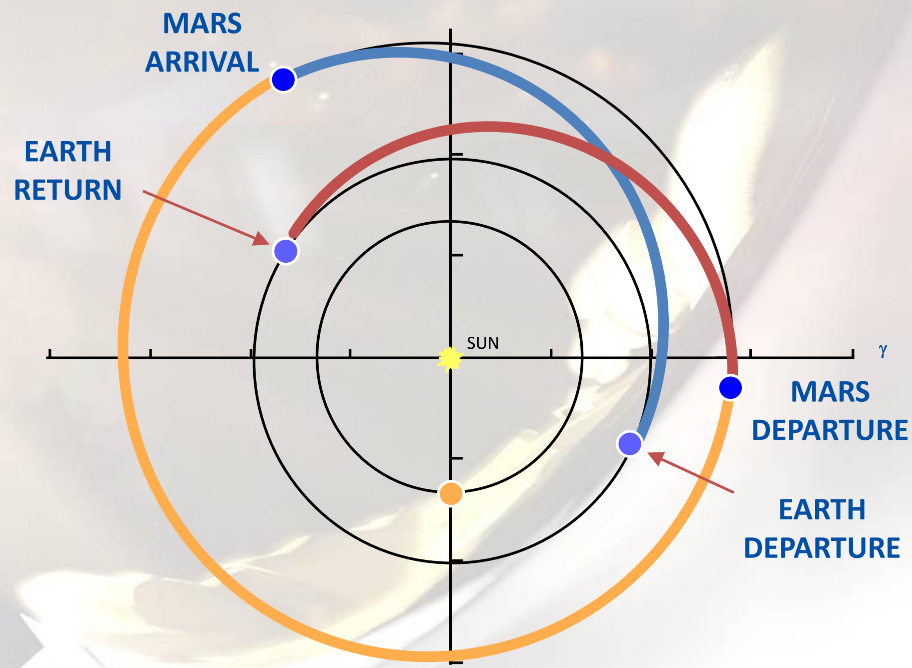
Mars-Phobos-Deimos conceptual mission is currently not a NASA DRM, but it could be!

Mars Ballistic Trajectory Classes – Mars Orbital

- **A trip to Mars with a return back to Earth is a double rendezvous problem.**
  - The first rendezvous outbound, with Mars, must be dealt with considering its influence on the second rendezvous, inbound with Earth.
  - Practical considerations dictate favorable, and different, planetary alignments relative to the Sun for outbound and inbound transfers.



Short-Stay Missions (Opposition Class)
Variations of missions with short Mars surface stays and may include Venus swing-by.



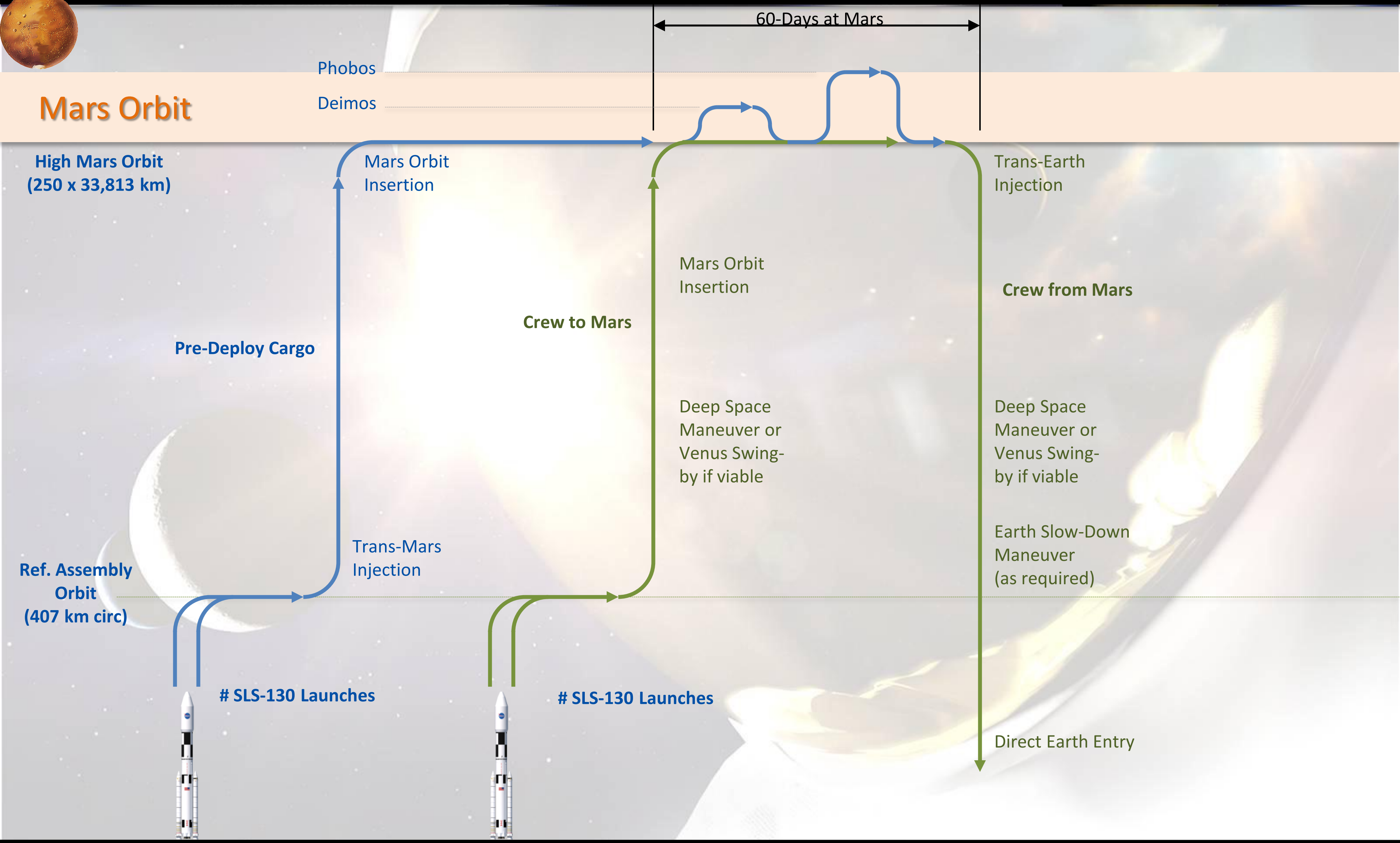
Long-Stay Missions (Conjunction Class)
Variations about the minimum energy mission.

Earth-Mars-Earth Missions - Key Considerations

- **Short-Stay (Opposition Class) Missions**
  - Non-optimum transfers which result in greater energy requirements – total transfer energy increases as stay time increases.
  - Characterized by relatively short periods in spent in the vicinity of Mars (generally 30-60 days).
  - In such, these missions will tend to be highly scripted with pre-planned operational timelines.
  - Due to the short time at Mars, there will be less time available for mission re-planning due to contingencies or large unanticipated discoveries.
- **Long-Stay (Conjunction Class) Missions**
  - “Minimum Energy” transfers both outbound to, and inbound from, Mars.
  - Characterized by long stay in the vicinity of Mars (330-560 days) and overall long mission durations (900+ days).
  - These long stay missions provide ample time for re-planning mission operations.
  - It is envisioned that upon arrival at Mars a very pre-planned scripted operational scenario will be followed. As the mission evolves, a more free-flowing collaborative (with Earth) scenario would follow.

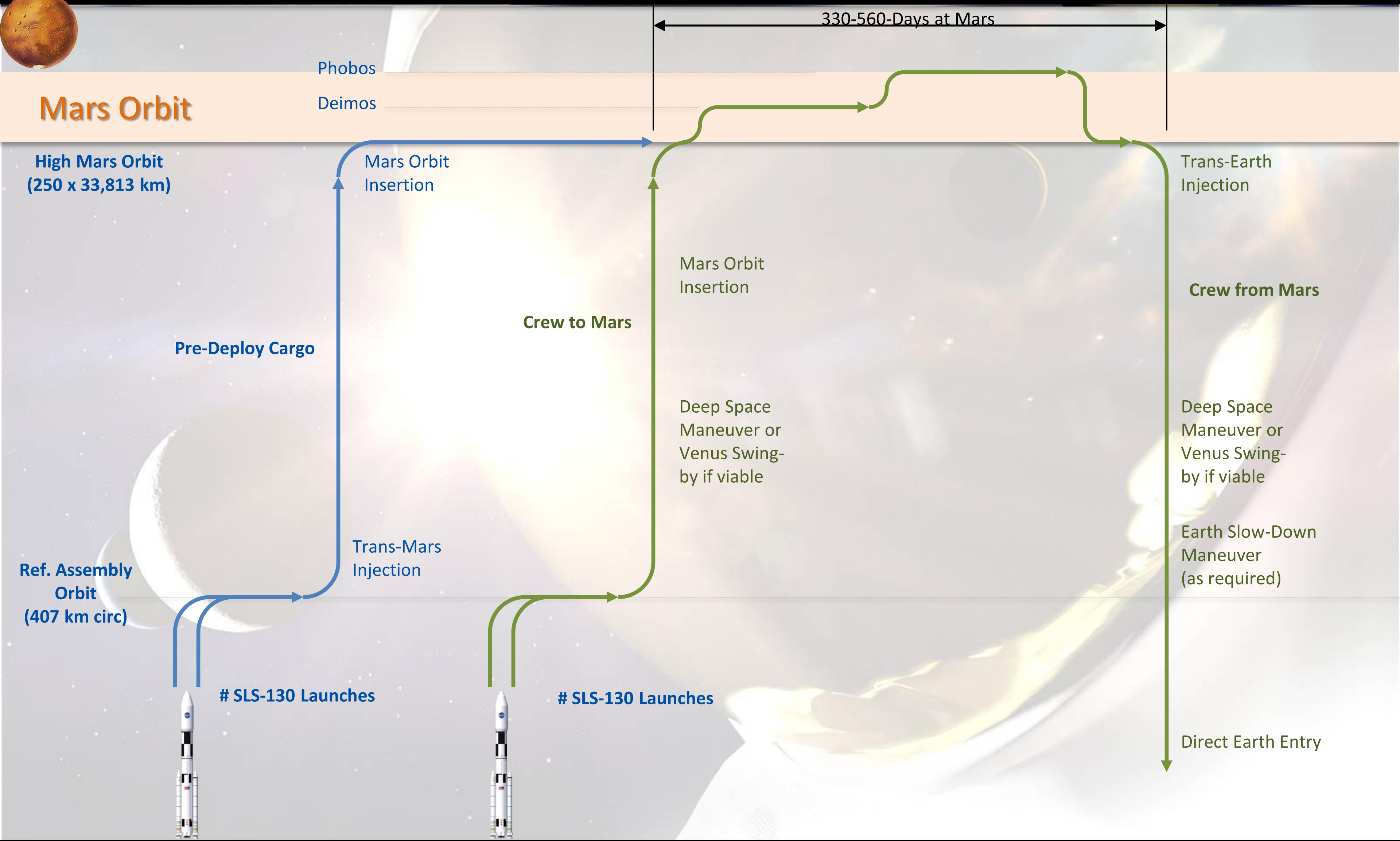
Short Stay Orbital Mission Concept

High Thrust Missions



Long Stay Orbital Design Reference Mission

High Thrust Missions

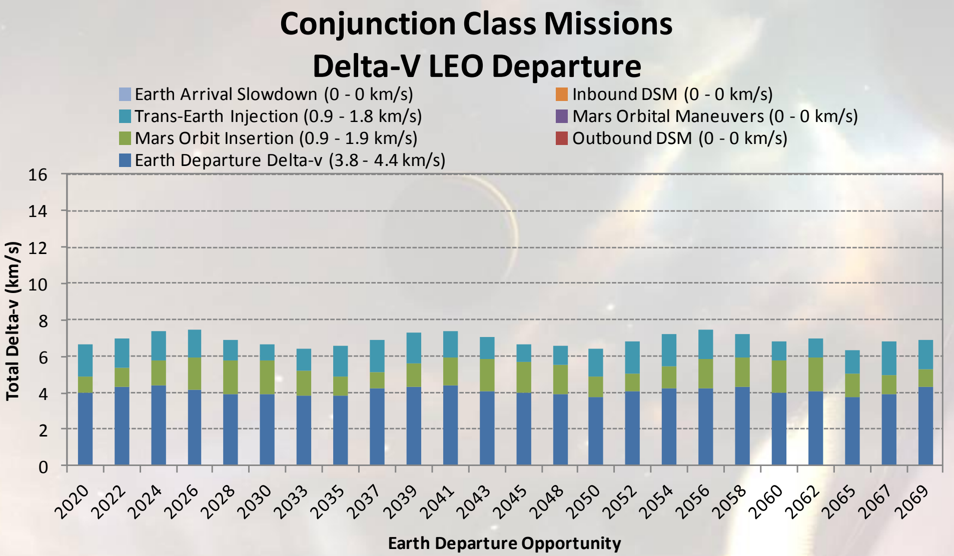


Mission Parameters for Typical Missions

Crew Mission from LEO to Mars Orbit and Return

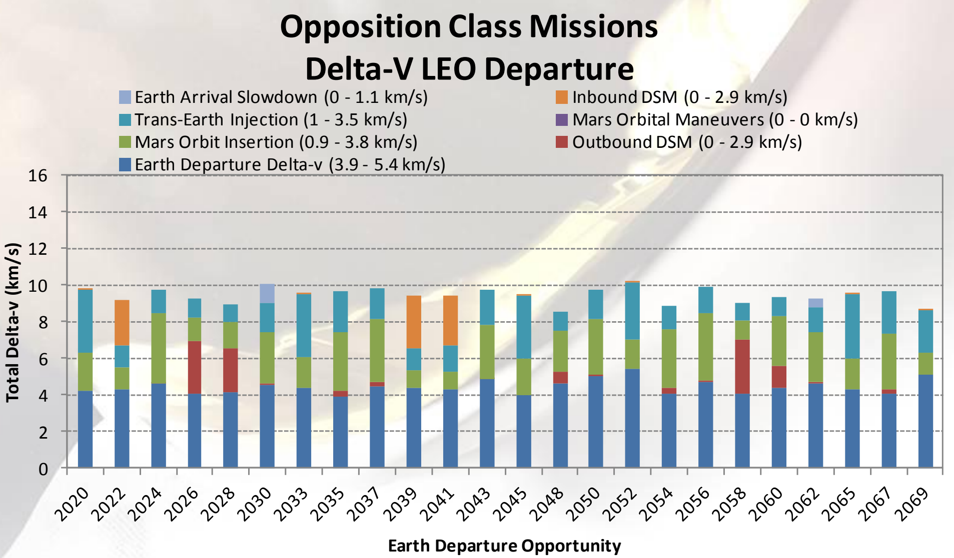
Conjunction Mission Assumptions:

- These ΔVs are for the crew vehicle from LEO, to Mars orbit, and return (green leg of the bat charts). Orbital maneuvers required for exploration in the Martian system not included
- 400 km circular orbit at Earth, free choice of inclination
- Propulsive capture into 1-Sol equatorial orbit at Mars (250 x 33,813 km)
- Direct Earth entry up to 12.2 km/s

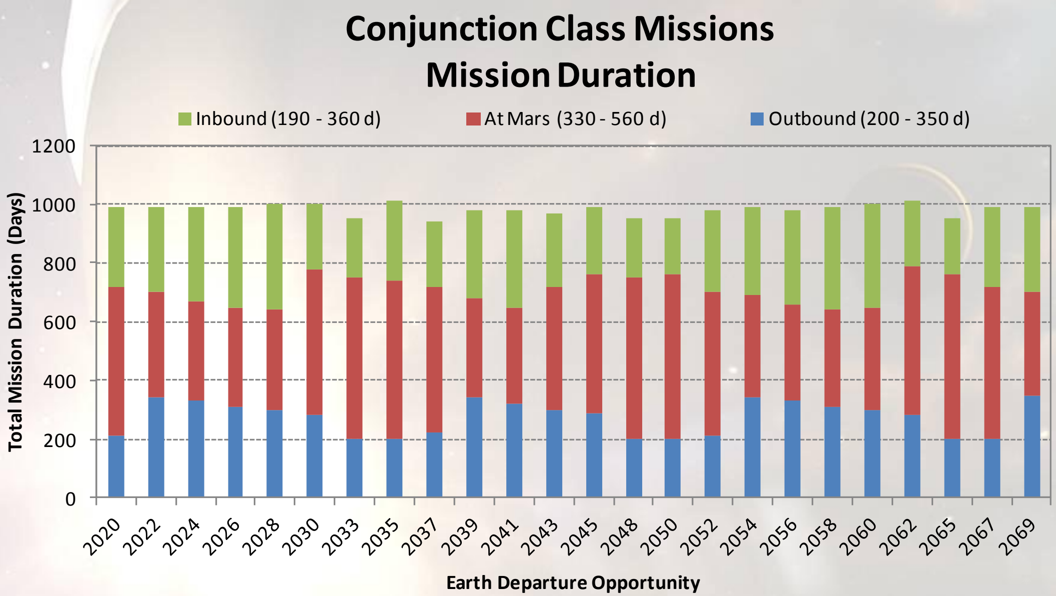


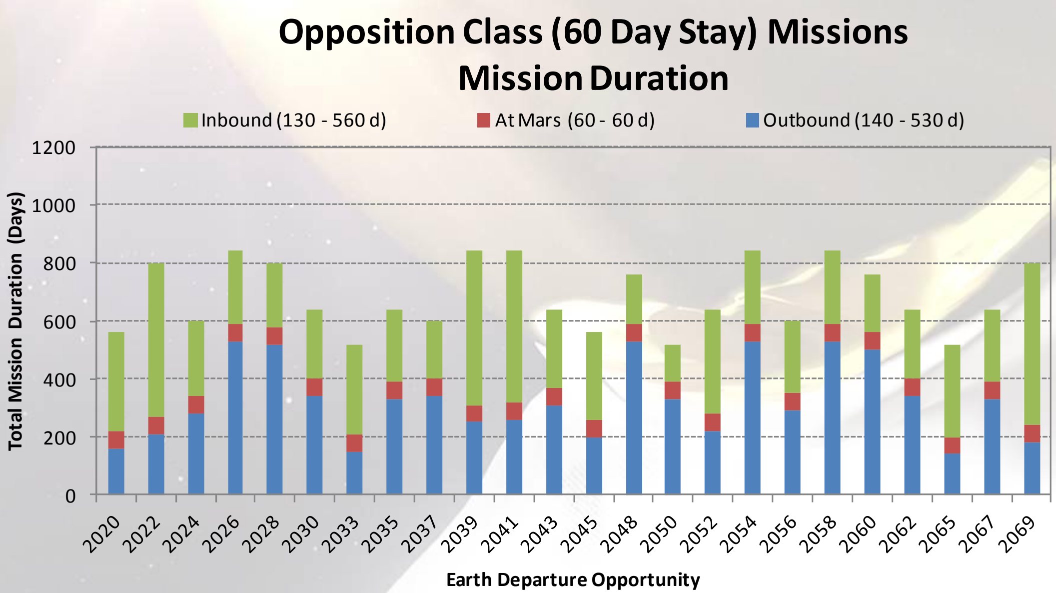
Opposition Mission Assumptions:

- These ΔVs are for the crew vehicle from LEO, to Mars orbit, and return (green leg of the bat charts). Orbital maneuvers required for exploration in the Martian system not included here.
- 400 km circular orbit at Earth, free choice of inclination
- Propulsive capture into 1-Sol orbit at Mars (250 x 33,813 km)
- Plane change to capture into departure orbit at Mars arrival
- Up to 60 days in Martian system (arrival to departure)
- Does not include orbital maneuvers required for exploration in the Martian system
- Direct Earth entry up to 13.0 km/s



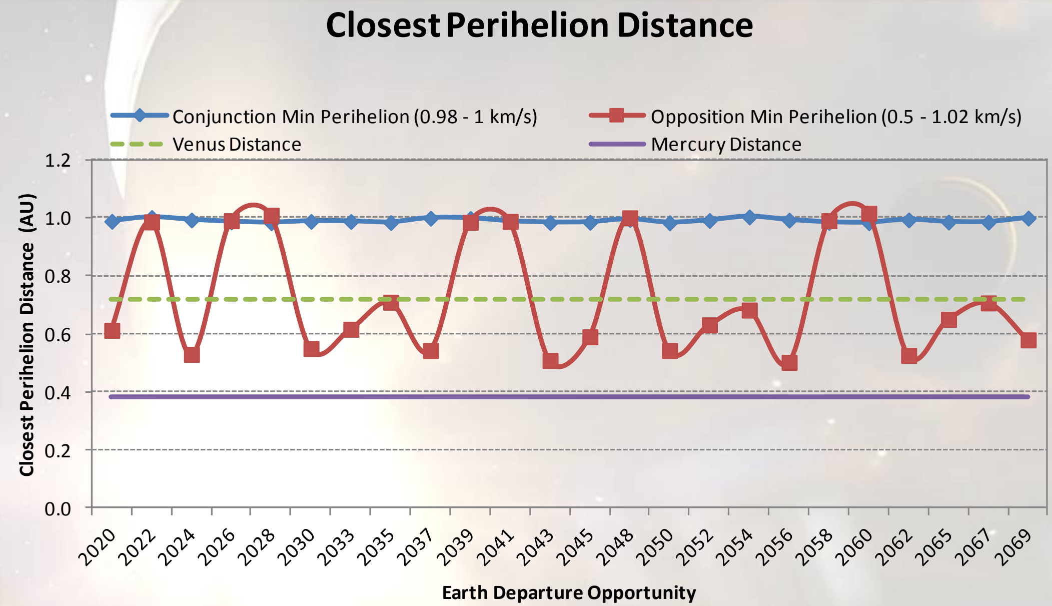
Example Variation in Mission Duration

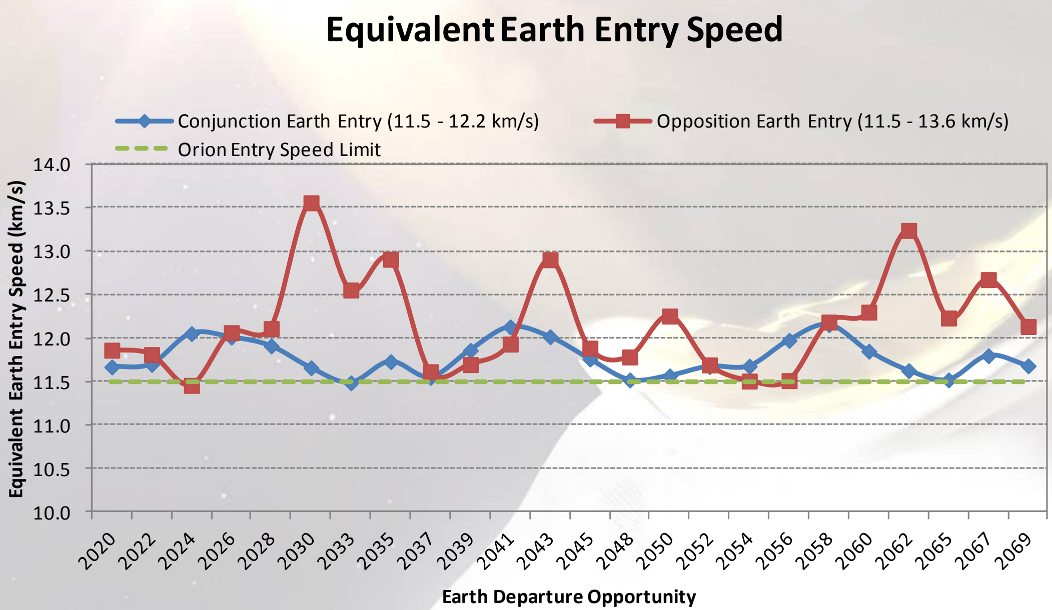




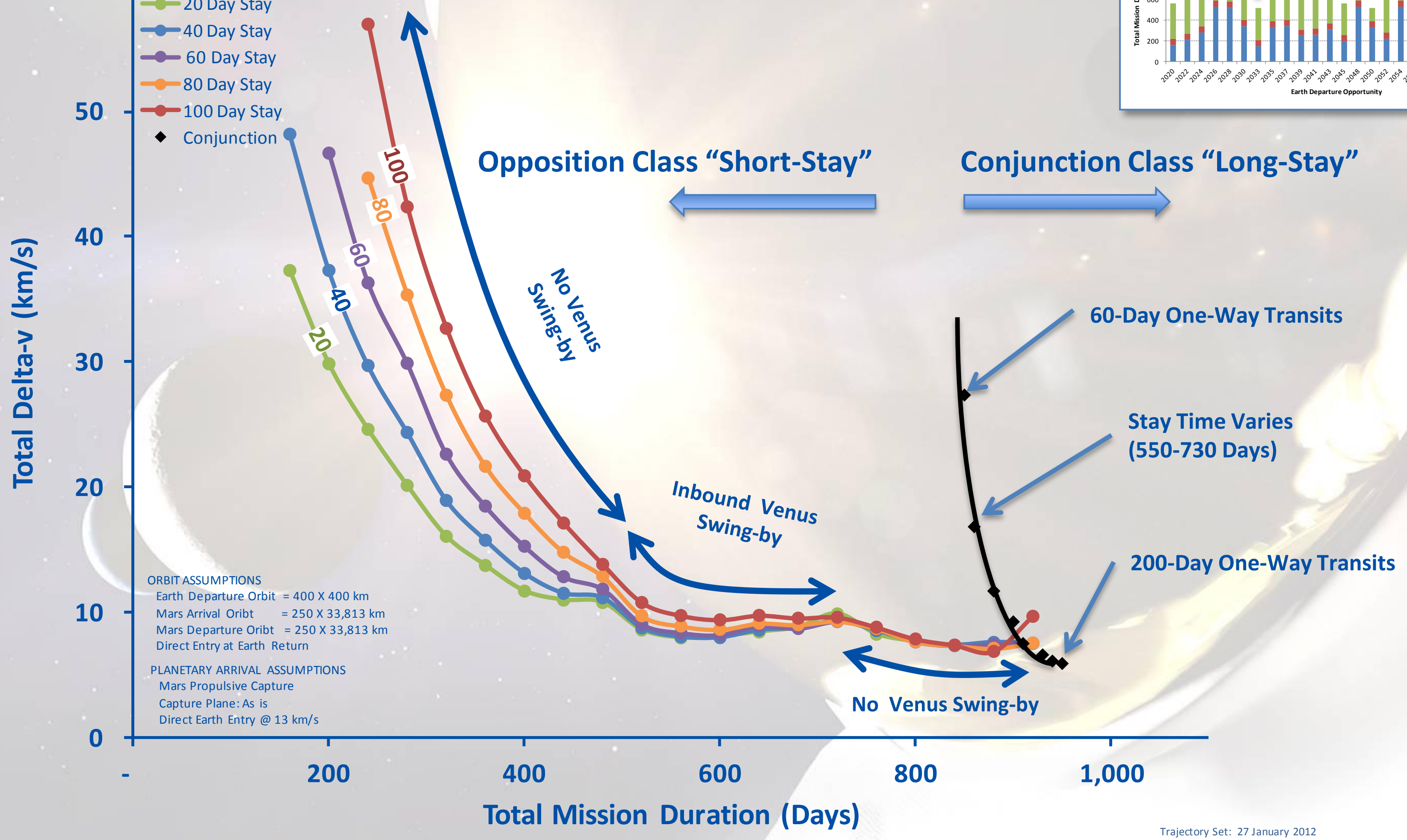
Mission Parameters for Typical Missions

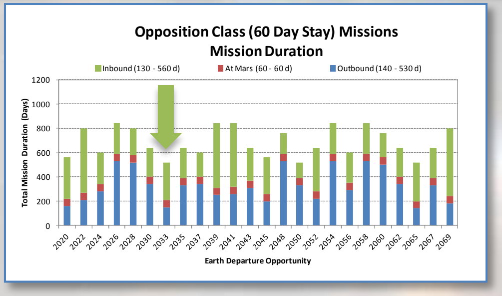
Mass Constrained Trajectories





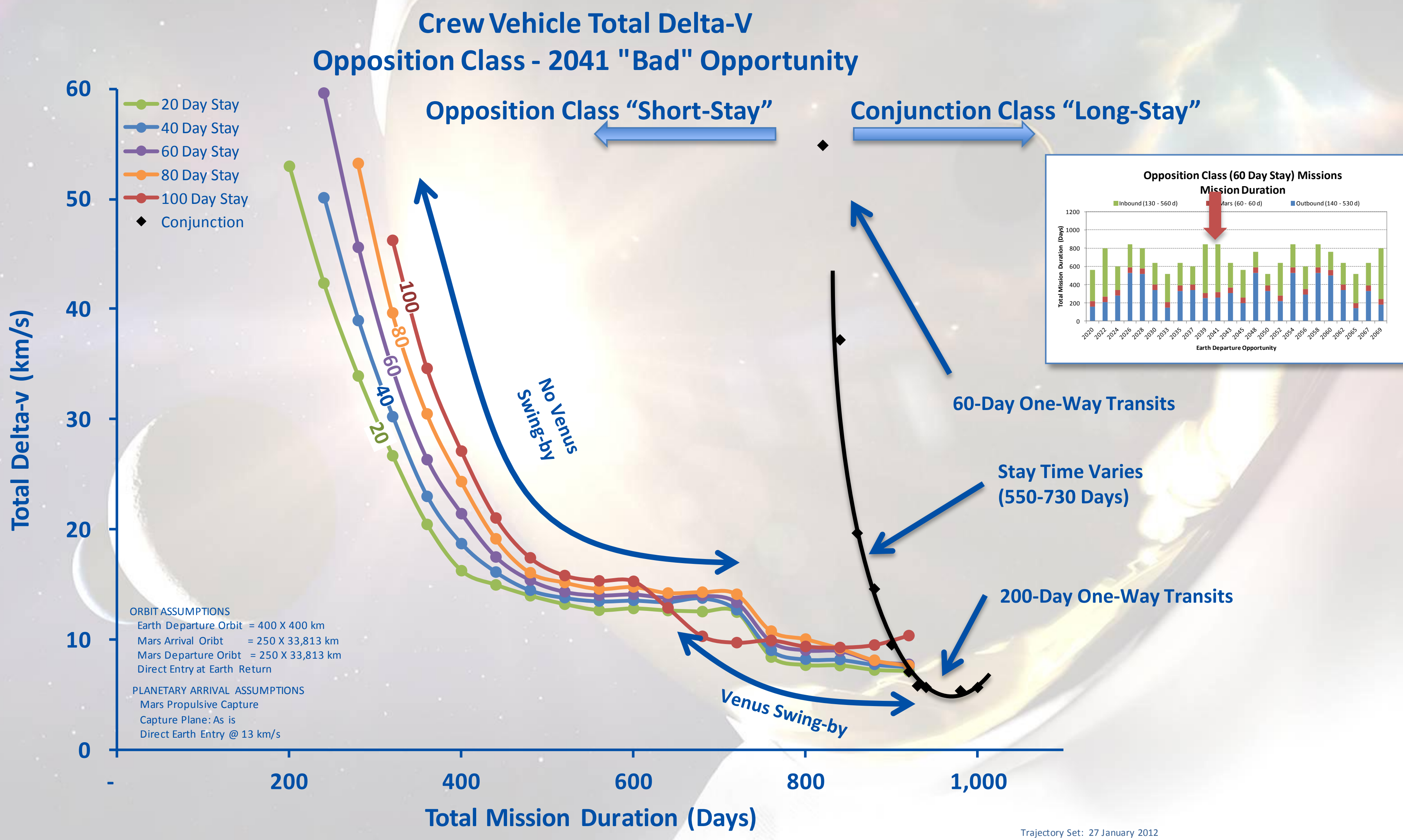
Example ΔV* versus Mission Duration – 2033 Opportunity





* ΔVs do not include any orbital maneuvers required at Mars

Example ΔV* versus Mission Duration – 2041 Opportunity



* ΔVs do not include any orbital maneuvers required at Mars

Transportation and Exploration Systems Assumptions

Space Exploration Vehicle

- Primary purpose is for exploration of the moons
- Crew of 2 for 14 days
- Nominal mass = 6.7 t
- CH_4 Stage when needed:
  - Stage Fraction: 15%
  - Isp: 355 s

Multi Purpose Crew Vehicle

- Same assumptions as HAT
- CM inert = 9.8 t
- SM inert = 4.5 t
- SM specific impulse = 328 s

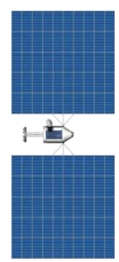
Deep Space Habitat

- Sizing consistent with HAT Cycle-C
- Mass Range : 28-65 t
- Consumables loaded based on crew size & mission duration

Chemical Propulsion Stage

- Sizing consistent with HAT Cycle-C
- Parametric design with each stage optimized
- Zero-boiloff cryo management
- Stage fraction ~ 23%
- Specific impulse = 465 s

Solar Electric Propulsion

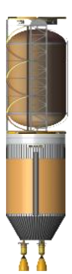


- Consistent with HAT
- Spacecraft alpha ~30 kg/kw
- Specific impulse = 1800-6000 s
- Xe tank fraction = 5%
- Total power varies

Nuclear Electric Propulsion

- Spacecraft alpha ~20 kg/kw
- Specific impulse = 1800-6000 s
- Xe tank fraction = 5%
- Total power varies

Nuclear Thermal Propulsion



- Consistent with Mars DRA 5
- NERVA-derived common core propulsion (20 t core)
- 3 x 111 kN engines
- Specific Impulse = 900 s
- All LH2 fuel with zero boil-off
- Drop tanks @ 27% tank fraction

Space Launch System

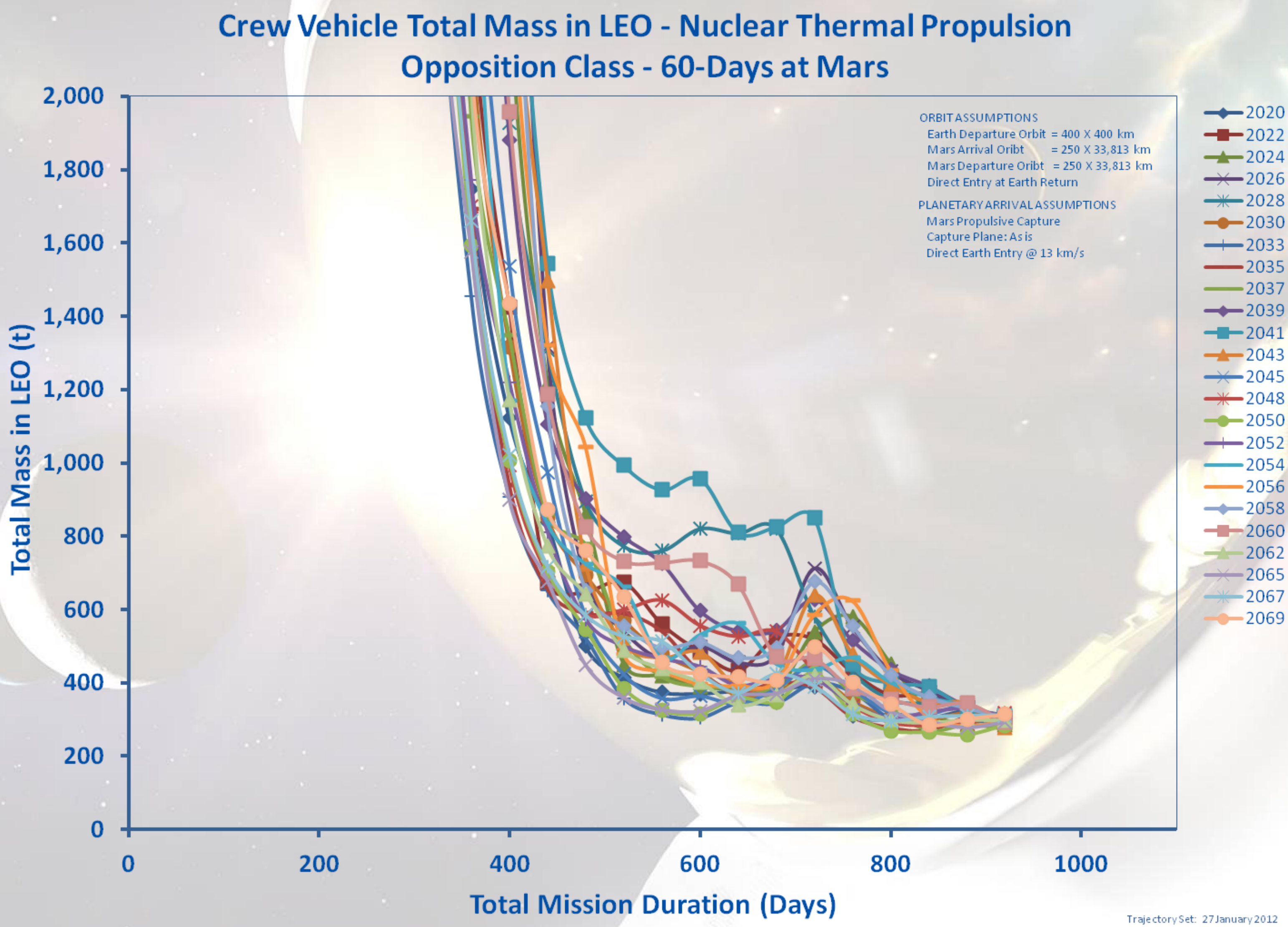
- Gross Performance ~ 130 t
- Net Performance ~ 120.4 t (HAT assumptions for reserve and adapters)
- Performance estimates to negative perigee conditions: (-87 km x 241 km)

Mars Landers

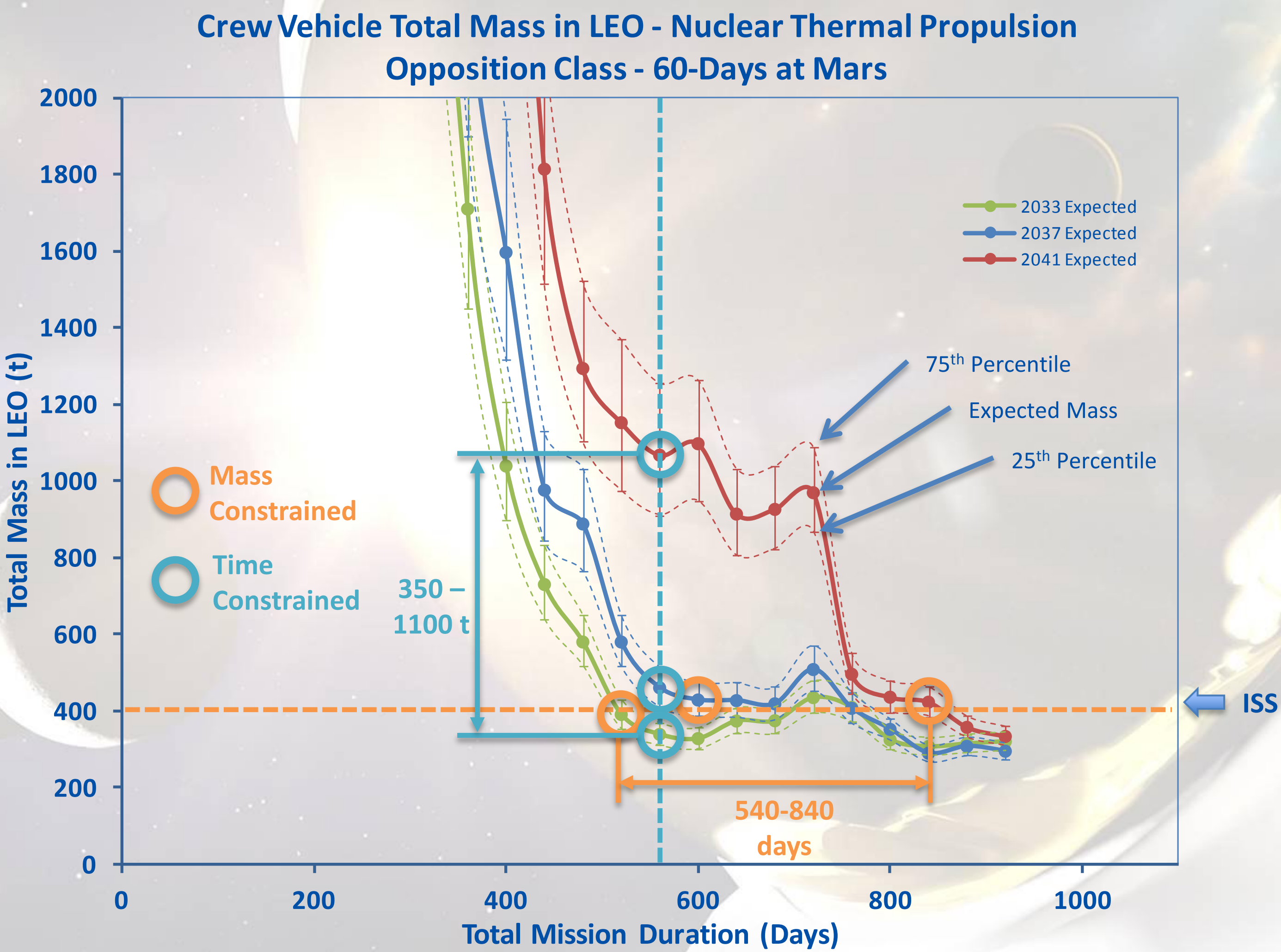
- Based on HAT Cycle-C and JPL Team-x Sizing
- Inflatable (HIAD) entry system
- Wet lander mass: 85 t
- Gross landed payload: 40 t

Crew Vehicle Mass as a Function of Mission Duration

Nuclear Thermal Propulsion – Expected Mass



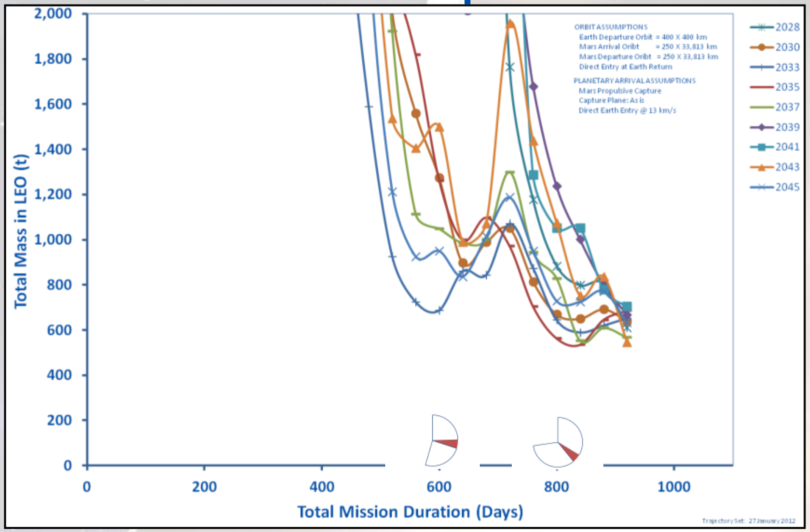
What Drives the Mission? Mass or Time?



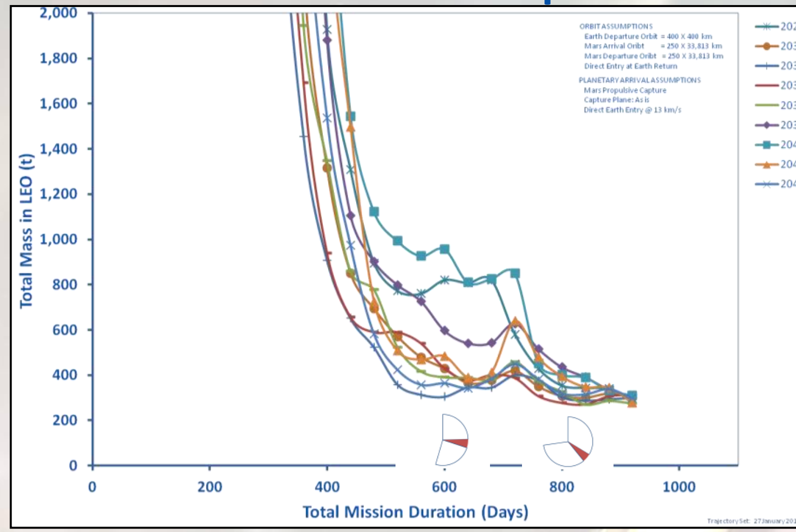
Propulsion Technologies and Stay Time

Round Trip Missions with 60 Days at Mars for Exploration

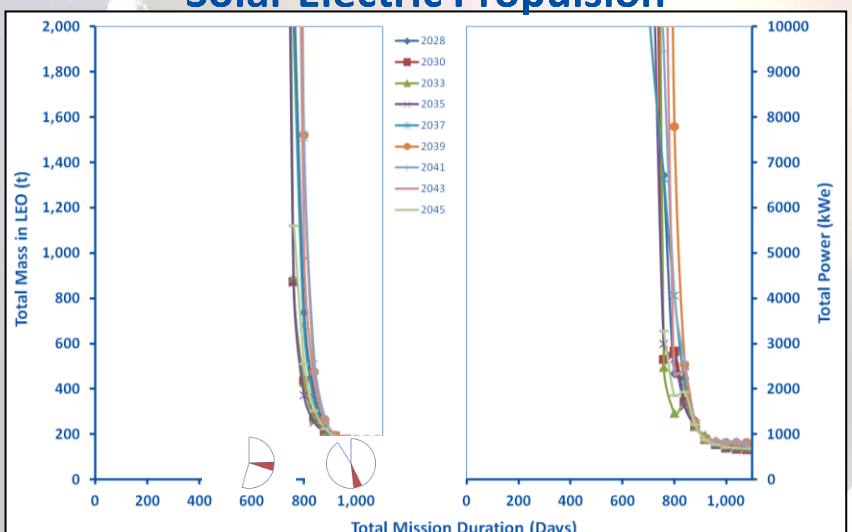
Chemical Propulsion



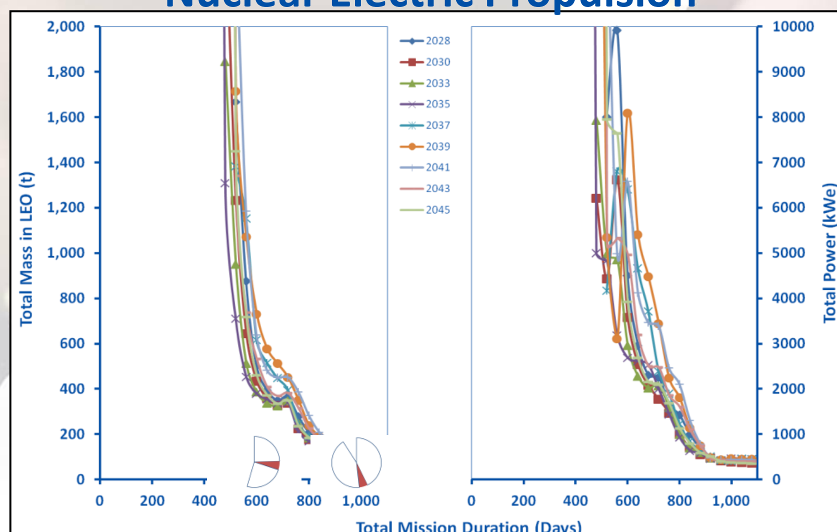
Nuclear Thermal Propulsion



Solar Electric Propulsion



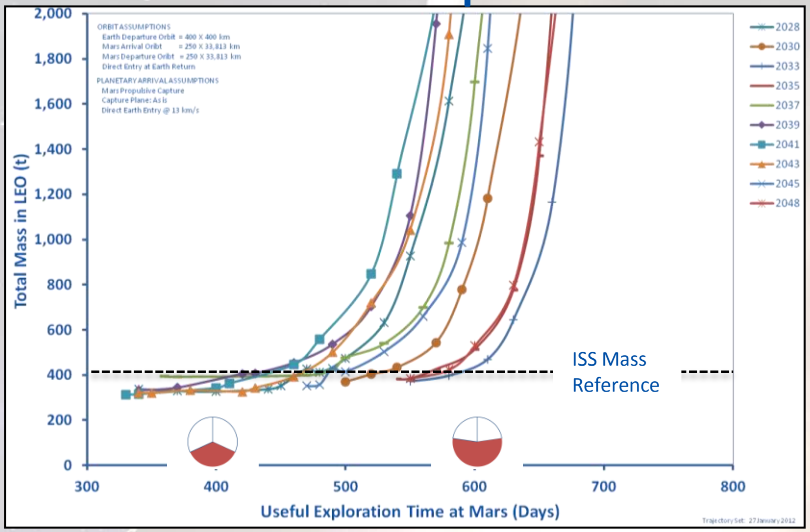
Nuclear Electric Propulsion



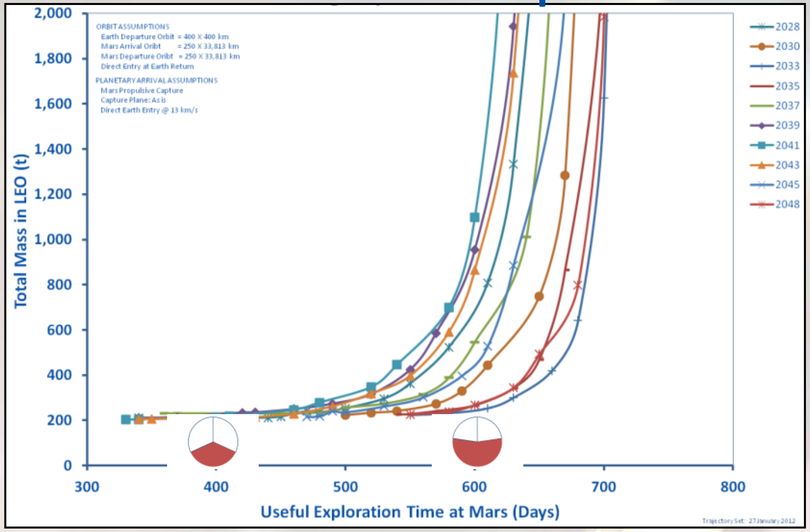
Propulsion Technologies and Stay Time

1100-Day Class Missions with 300+ Days at Mars for Exploration

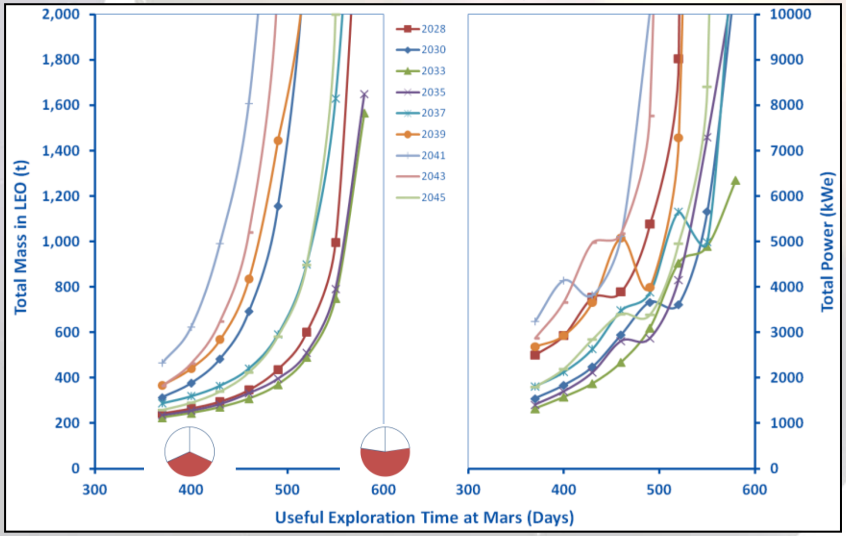
Chemical Propulsion



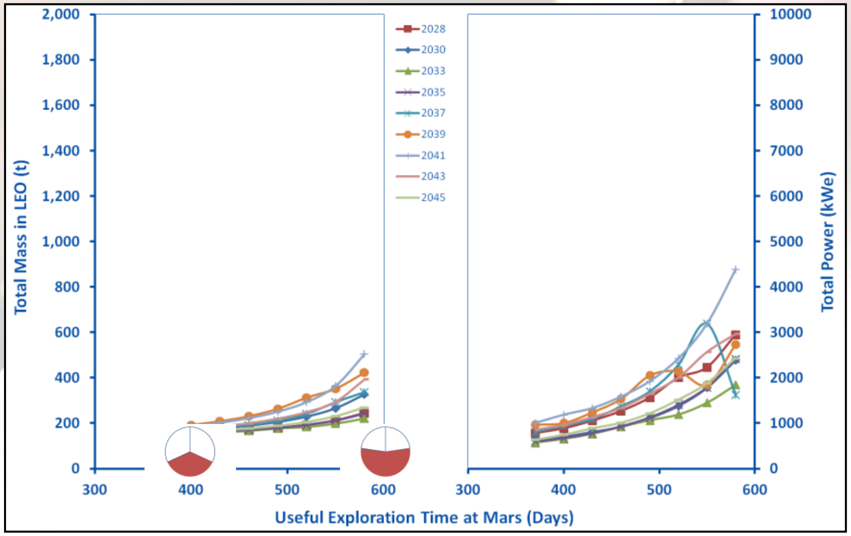
Nuclear Thermal Propulsion



Solar Electric Propulsion



Nuclear Electric Propulsion



Key Mission Comparisons

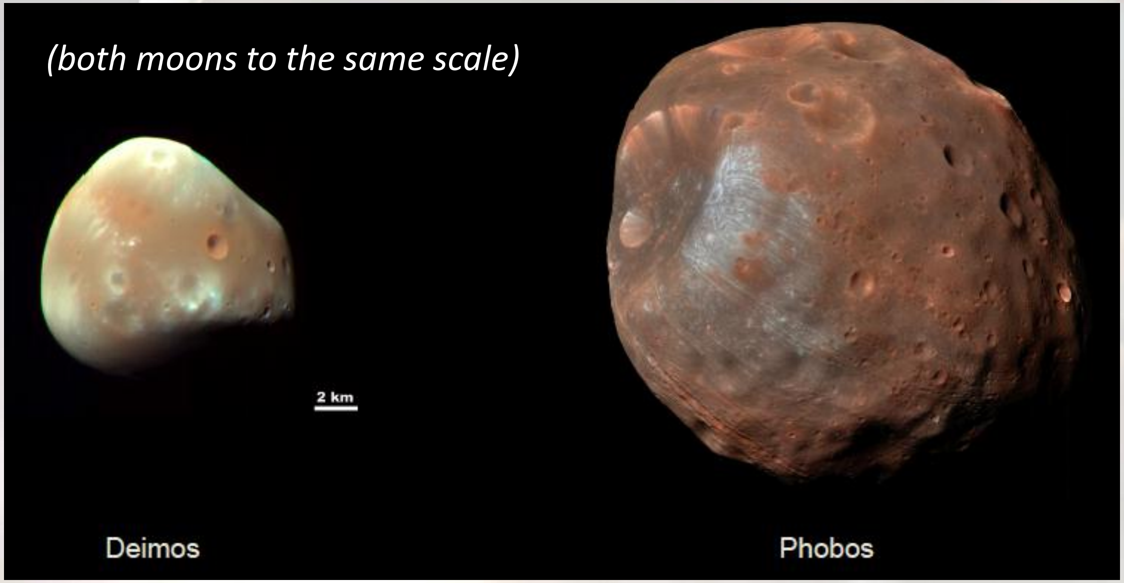
	Short-Stay Mass Constrained	Short-Stay Time Constrained	Long-Stay
Orbital Missions			
Crew In-Space Delta-v (km/s)	8.2-9.7	8.3-14.1	8.9-10.3
Vicinity Delta-v (km/s)	~1.7-3.2 x 2	~1.6-2.6 x 2	(included above)
Total Mission Duration (days)	520-840	560	920-940
To and From Mars (days)	480-760	500	360-440
Time at Destination (days)	60	60	480-580
Earth Entry Speed (km/s)	11.5-13.6	11.4-12.6	11.5-12.2
Closest Perihelion Passage (AU)	0.5	0.5	0.99
Crew Mission Mode	Artificial-g?	Artificial-g?	Artificial-g?
Cargo Pre-Deployed	SEVs + Stages	SEVs + Stages	SEVs
Surface Missions			
Crew In-Space Delta-v (km/s)	Same	Same	6.0-7.1
Descent/Ascent Delta-v (km/s)	~6.0	~6.0	~6.0
Total Mission Duration (days)	Same	Same	Same
To and From Mars (days)	Same	Same	Same
Time at Destination (days)	Same	Same	Same
Earth Entry Speed (km/s)	Same	Same	Same
Closest Perihelion Passage (AU)	Same	Same	Same
Crew Mission Mode	Same	Same	Zero-g
Cargo Pre-Deployed	Lander(s?)	Lander(s?)	Landers
	• Mass constraints tend to be the largest architectural driver. This strategy minimizes number of launches • Trip time can get quite long resulting in human health challenges. • Close perihelion passage remains a human health challenge • Higher entry speeds require slowdown maneuvers	• Total delta-v drives excessive mission mass and number of launches • 560 days remains a key human health challenge (zero-g and GCR) • Close perihelion passage remains a human health challenge • Moderate entry speeds still require slowdown maneuver	• Results in both lower and consistent delta-v, entry speeds, mission mass and resulting number of launches • Long missions drive reliability • Transits within current knowledge base • Human health issues remain for Mars stay for both orbit and surface

Mission Implementation Summary

- **Human Exploration of Phobos and Deimos are nominally conducted entirely in the deep space environment (zero-g, radiation).**
- **Practical considerations (e.g., transportation technology and number of launches) will limit mission durations to not much less than 600 days. Thus, human health issues cannot be obviated by propulsion technology alone.**
- **For these types of missions emphasis is usually placed on:**
  - Reducing the total mission duration to minimize crew exposure to the risks of the deep-space environment;
  - Providing sufficient time in Mars orbit.
- **Unfortunately, for round-trip Mars missions, these two desires work against each other. Need to find the right balance of maximizing return while reducing crew risk.**
- **If there is no significant difference between 600 and 900 days from human health or overall mission risk and operations perspectives, then long-stay (conjunction-class) missions offer the advantage of lower overall mission mass and longer time in the Mars system for exploration activities. However, other factors (e.g., cost, risk, and value of additional science/exploration time) must be taken into account before reaching a conclusion on the most appropriate mission mode to achieve mission objectives.**

Introduction to Phobos and Deimos

This color-enhanced view of Deimos, the smaller of the two moons of Mars, was taken on Feb. 21, 2009, by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. Deimos has a smooth surface due to a blanket of fragmental rock or regolith, except for the most recent impact craters.



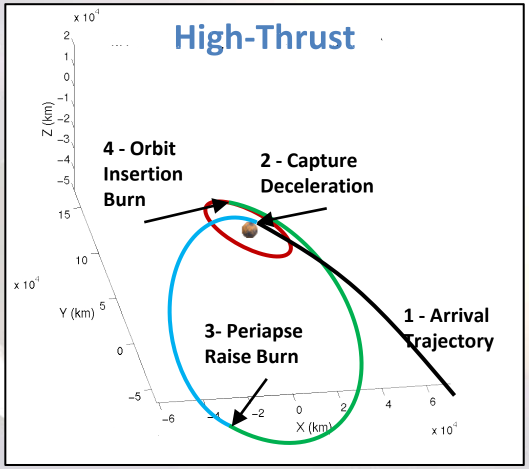
The High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter took this image of Phobos on March 23, 2008. This was taken from a distance of about 6,800 kilometers. It is presented in color by combining data from the camera's blue-green, red, and near-infrared channels.

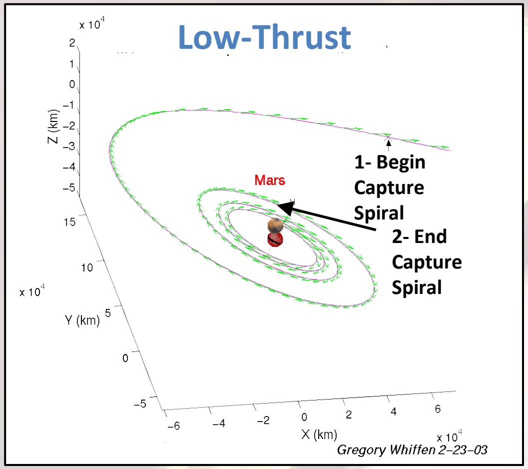
Mass (kg)	**1.80 × 10^{15}**
Dimensions (km)	**15.6 × 12.0 × 10.2**
Albedo	**0.068**
Equatorial Surface Gravity (μg)	**400**
Semi-Major Axis (km)	**23,459 (Mean)**
Inclination (deg.) (to Mars Equator)	**0.93**
Rotation Period (sols)	**1.23 (Synchronous)**
Density (g/cm³)	**1.54 ± 0.23**
Albedo & Composition	**0.021±0.006: rich in carbonaceous material (water?); similar to (D/C-type asteroids and carbonaceous chondrite meteorites**

Mass (kg)	**1.08 × 10^{16}**
Dimensions (km)	**26.2 × 22.2 × 18.6**
Albedo	**0.071**
Equatorial Surface Gravity (μg)	**860–190**
Semi-Major Axis (km)	**9,378 (Mean)**
Inclination (deg.) (to Mars Equator)	**1.09**
Rotation Period (sols)	**0.31 (Synchronous)**
Density (g/cm³)	**1.87 ± 0.06**
Albedo & Composition	**0.056±0.014: organic rich silicates; carbon and anhydrous silicates; possible interior water ice**

Mars Orbit Capture and Departure Dynamics

- Both Phobos and Deimos are essentially in the equatorial plane of Mars, with nearly circular orbits at 9,378 km and 23,459 km, respectively.
- Earth-Mars trajectory arrival and departure geometries are not in the equatorial plane, thus additional orbital maneuvers (inclination change and orbit lower/raise) are required once the necessary crew parking orbit is established.



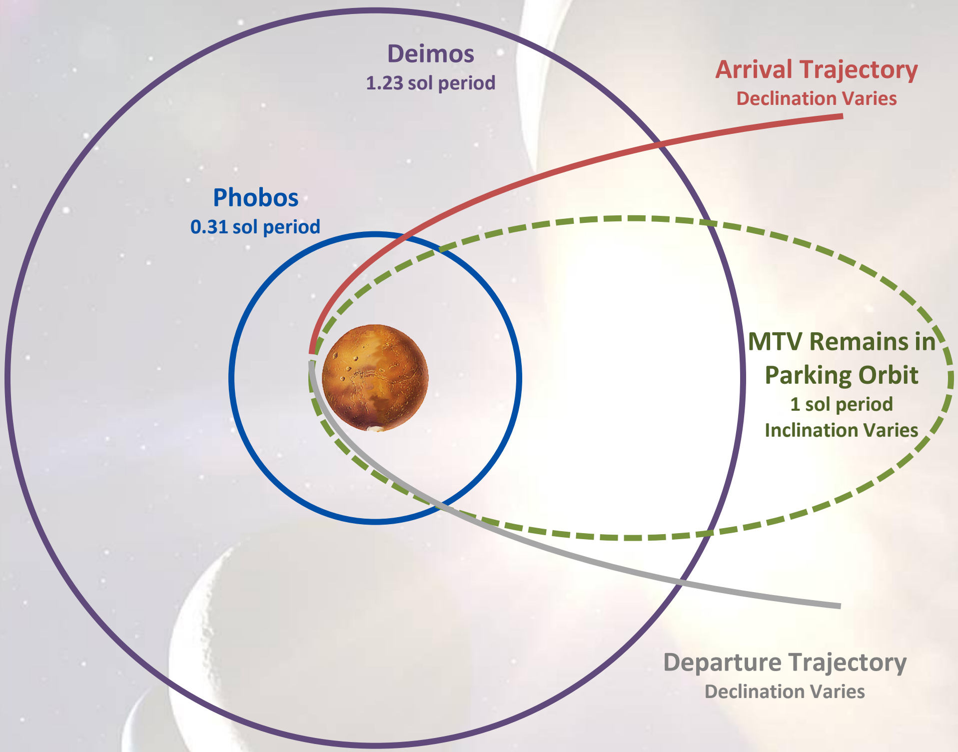


- Multi-burn strategy used to account for planar alignments.
- Capture time is short (hours to days) depending on parking orbit chosen.

- Plane adjustments made at Mars arrival (sphere of influence).
- Capture duration is long (weeks to months) depending on orbit and propulsion power level, Isp (thrust).

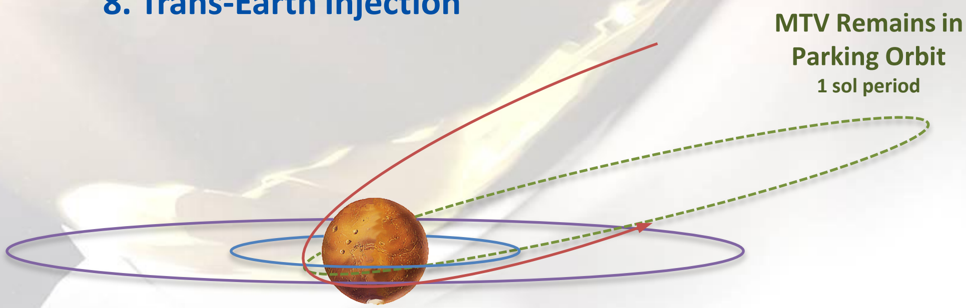
Short Stay Orbital Operations Concept

High Thrust Missions



Assumed Mars Orbit Strategy

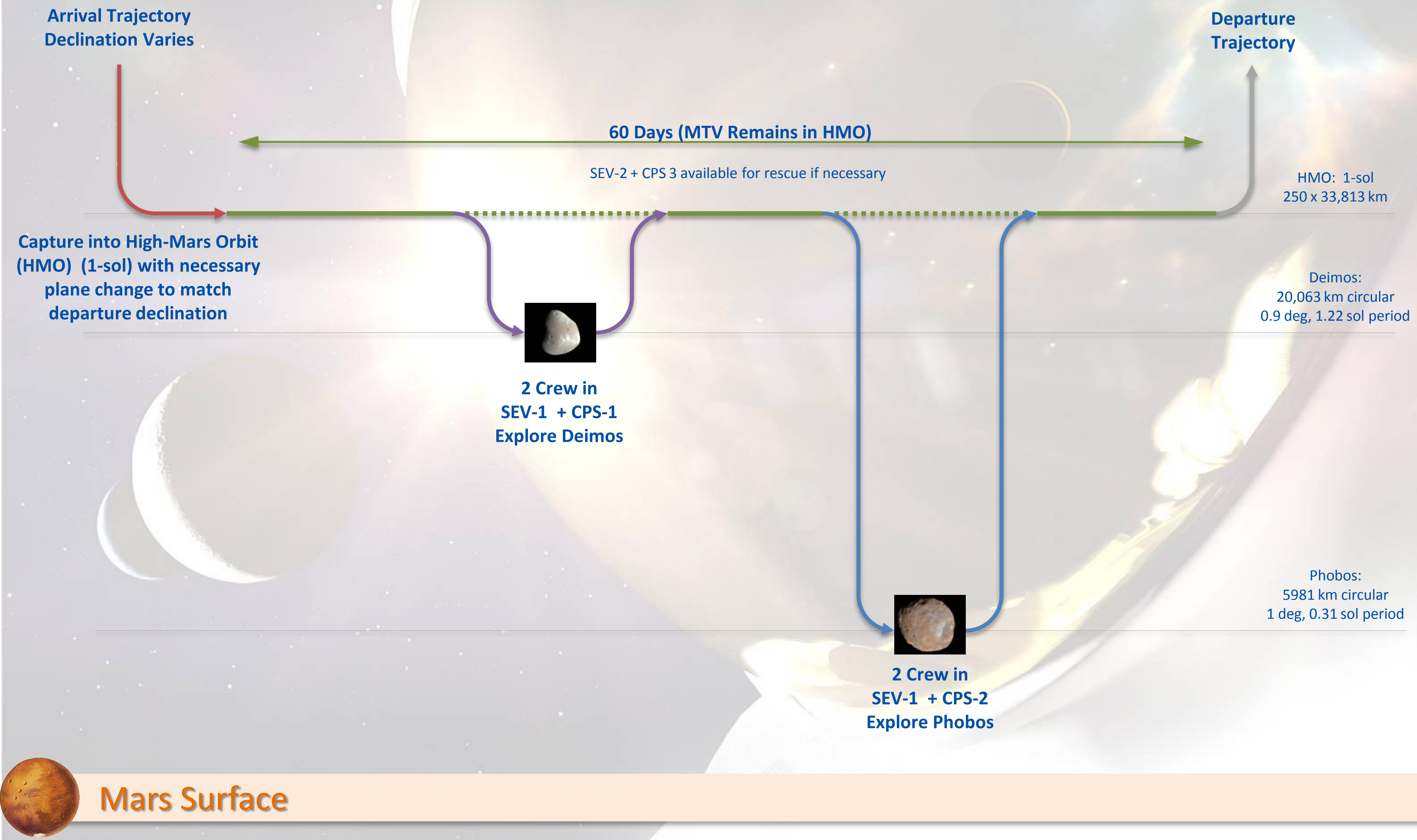
1. Cargo pre-deployed into a 1-sol parking orbit (250 x 33,813 km) with inclination matching crew Mars departure declination
2. Capture into a 1-sol parking orbit (250 x 33,813 km) with proper plane change to match departure declination
3. Leave Mars Transfer Vehicle (MTV) in 1-sol parking orbit
4. Prepare for orbital operations
5. Utilize SEV-1/CPS-1 to explore Deimos for 14 days (1,370-2,770* m/s delta-v required)
6. Utilize SEV-2/CPS-2 to explore Phobos for 14 days (1,700-3,170* m/s delta-v required)
7. Prepare for Mars departure
8. Trans-Earth Injection



* These values still under review

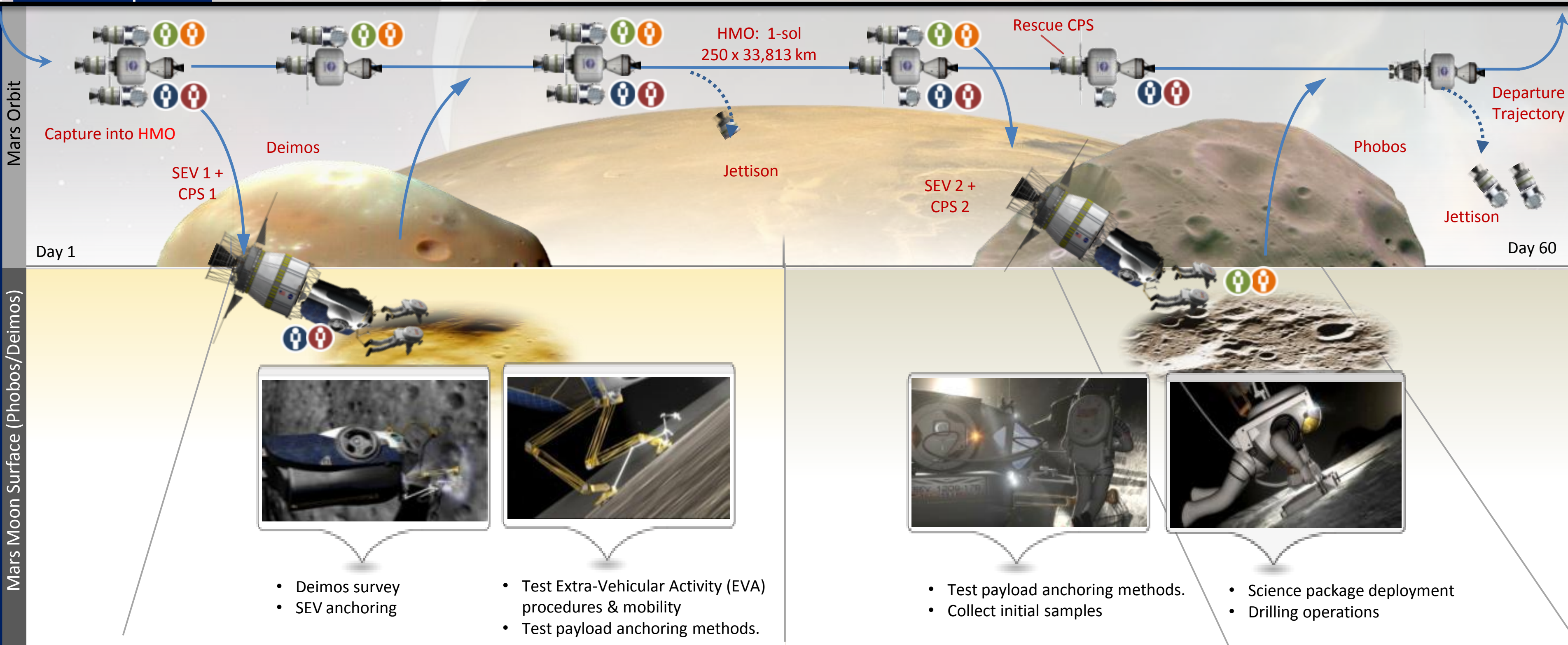
Short Stay Mars Vicinity Operations

High Thrust Missions



Short Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

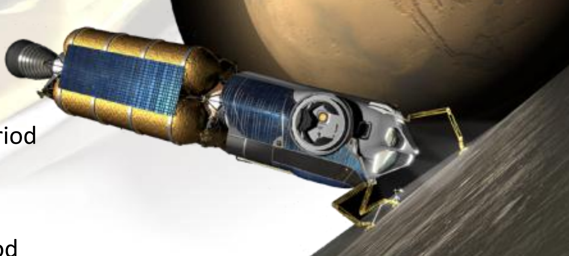
1. Capture into a 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave MTV in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,370-2,770 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for 14 days (1,700-3,170 m/s delta-v required)
6. Prepare for Mars departure
7. Trans-Earth Injection

Mission Site: Phobos / Deimos

Crew: 4

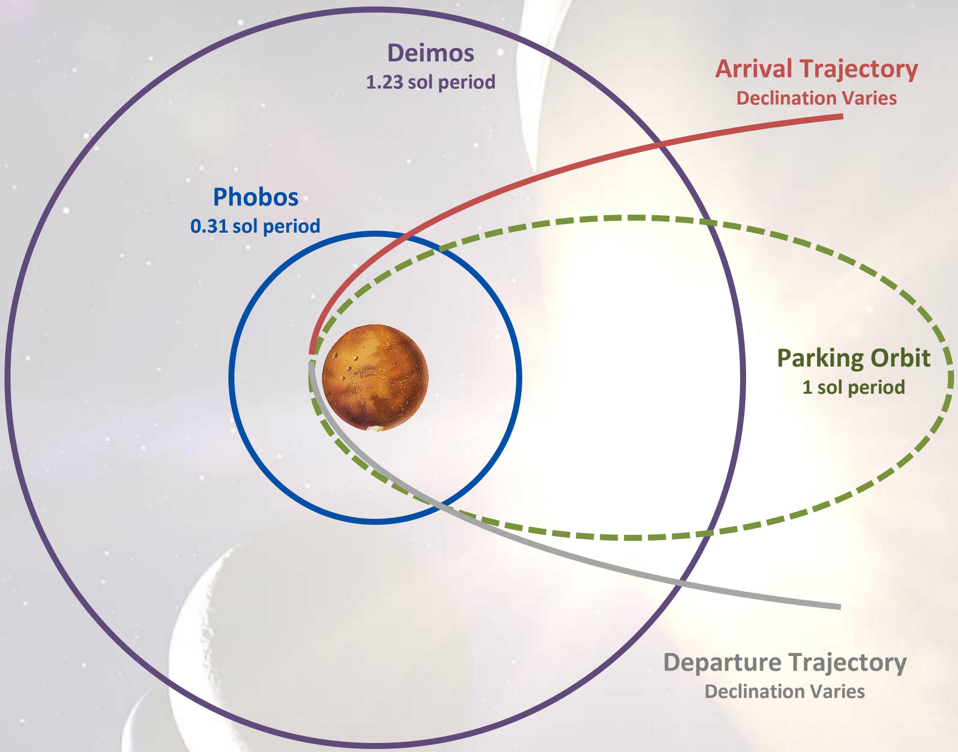
Deimos:
20,063 km circular
0.9 deg, 1.23 sol period

Phobos:
5981 km circular
1 deg, 0.31 sol period



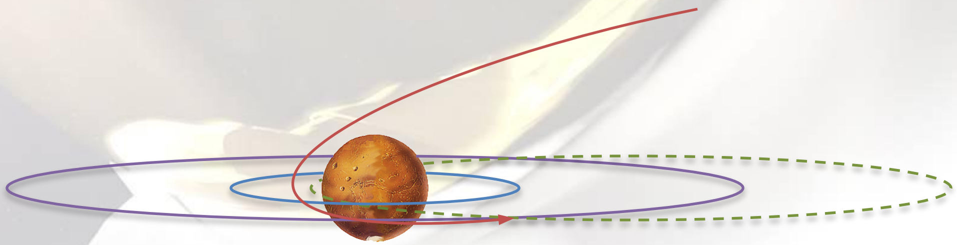
Long Stay Operational Concept

High Thrust Missions



Assumed Mars Orbit Strategy

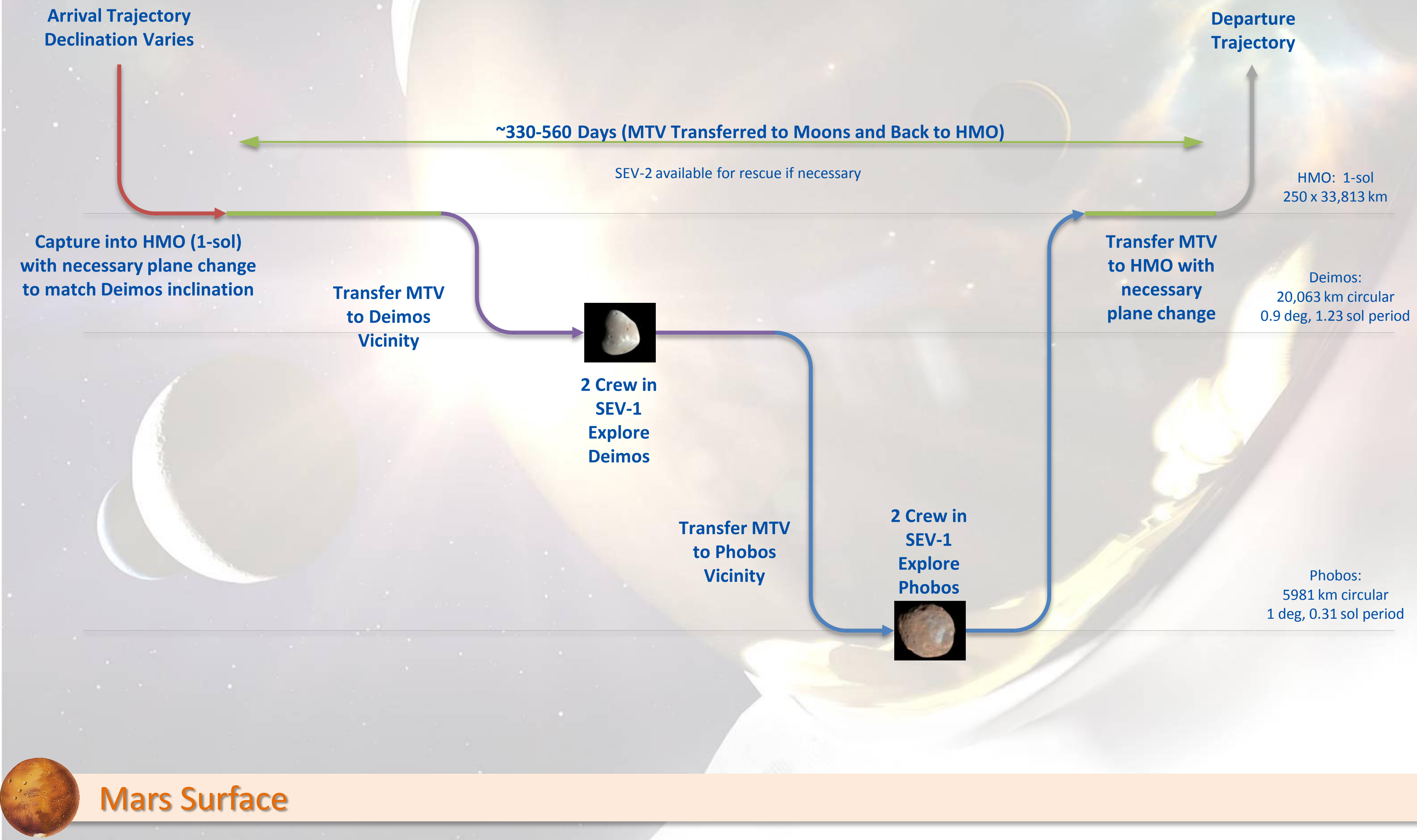
1. Capture into a 1-sol parking orbit (250 x 33,813 km) with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (767* m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit (816 m/s delta-v required)
6. Utilize SEV-2 to explore Phobos numerous times
7. Raise to 1-sol parking orbit (planar) (796* m/s)
8. Prepare for departure
9. Trans-Earth Injection including plane change



* These values still under review

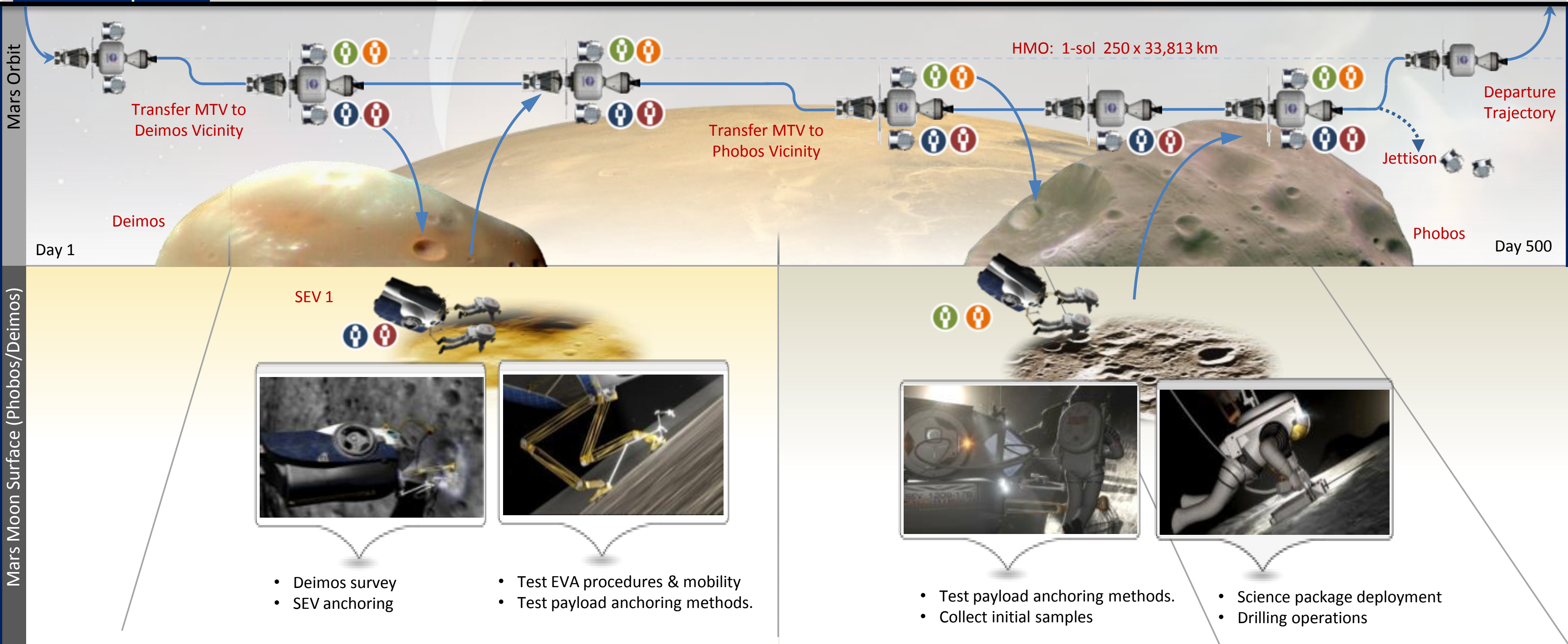
Long Stay Mars Vicinity Operations

High Thrust Missions



Long Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

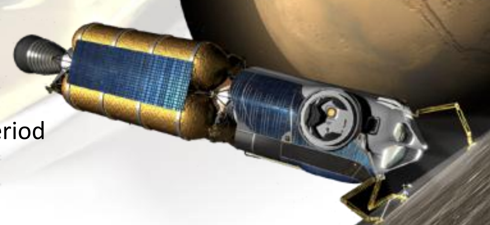
1. Capture into a 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower MTV to Deimos orbit (767 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower MTV to Phobos orbit (816 m/s delta-v reqd.)
6. Utilize SEV-2 to explore Phobos numerous times
7. Raise to 1-sol parking orbit (planar) (796 m/s)
8. Trans-Earth Injection including plane change

Mission Site: Phobos / Deimos

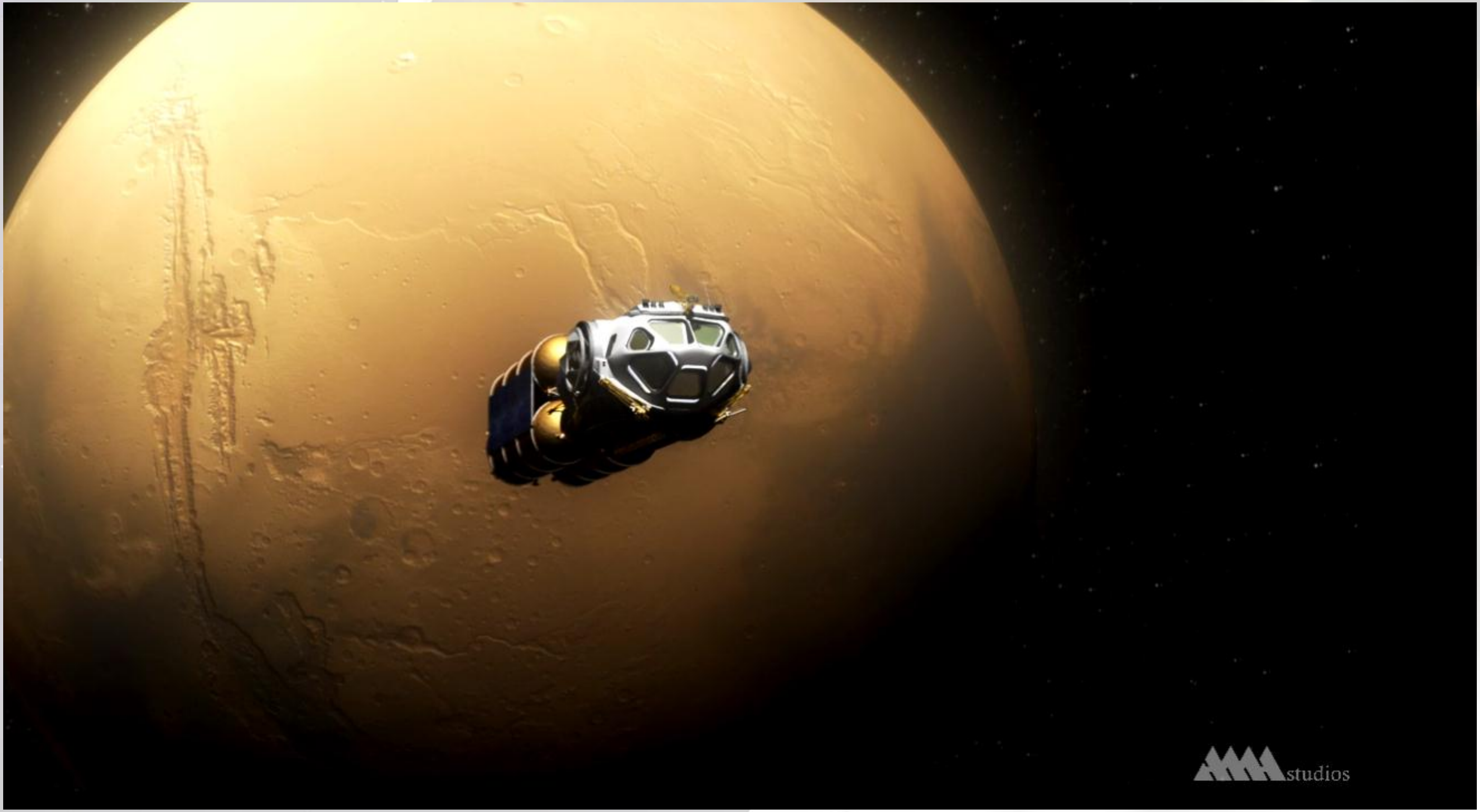
Crew: 4

Deimos:
20,063 km circular
0.9 deg, 1.23 sol period

Phobos:
5981 km circular
1 deg, 0.31 sol period



Animation of Martian Moons Mission



Animation Credit: NASA/AMA, Inc.

Mars-Phobos-Deimos (MPD) Destination Mission Concept (DMC) – Study Areas

Initial effort to identify the science and exploration objectives relevant for a such a mission. Defined activities/payloads necessary to fulfill each of those objectives

Converted activities/payloads into 2-hr building blocks that fully or partially fulfill multiple objectives require multiple payloads

Combined building blocks within mission implementation constraints to develop an existence proof DMC

Formulated overall mission exploration strategy options and preliminary analysis of trajectories within the Martian system to facilitate destination activities

Science Objectives

Exploration Objectives

→ "Building Blocks" → Destination Mission Concepts ↔ Mission Implementation

Robotic Precursor Requirements

NEA Human / Robotic Mission Synergies

Cis-Lunar Activity Synergies

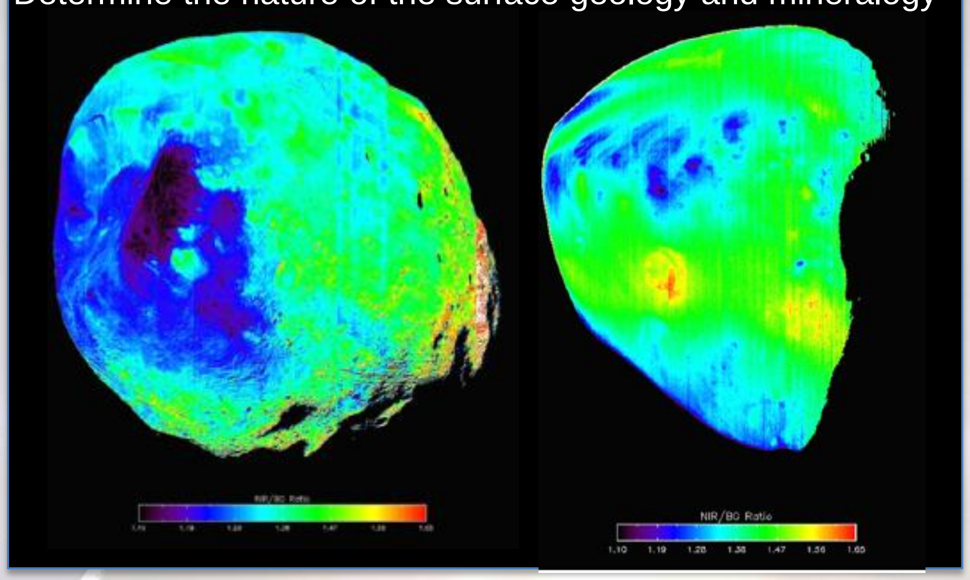
Identified strategic knowledge gaps (SKGs) and required robotic precursor measurements necessary to address them prior to human mission

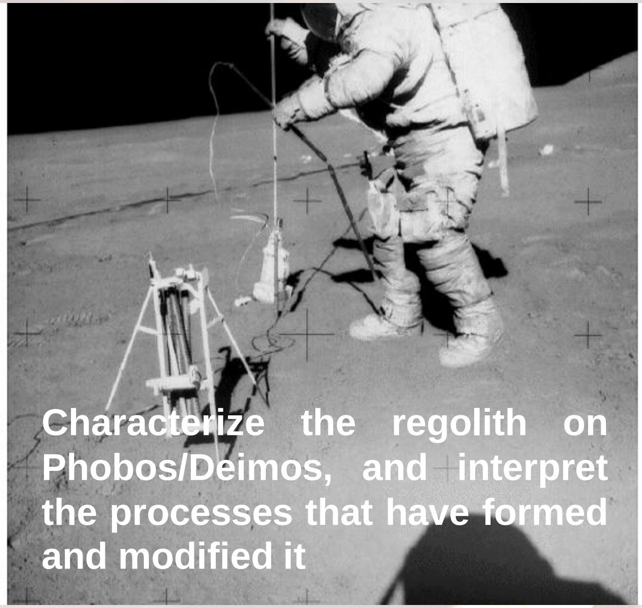
Identified synergies between human/robotic near-Earth asteroid (NEA) missions and an MPD mission. Determined the information/experience that could be gained from NEA missions prior to an MPD mission

Identified how cis-lunar space missions and activities can prepare for an MPD mission and how an MPD mission might enhance cis-lunar activities

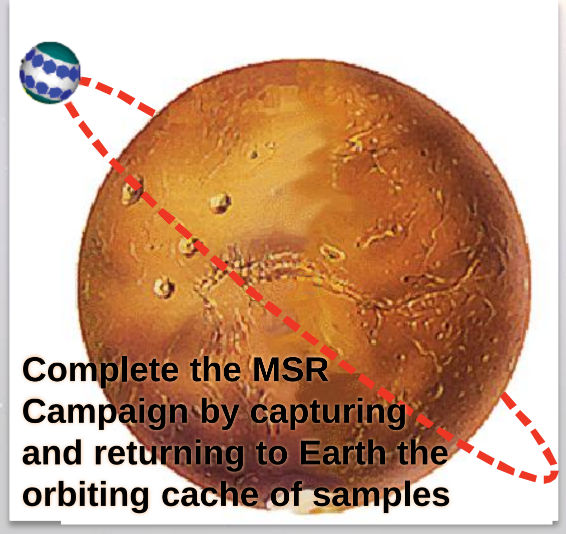
Primary Science Objectives for Human Martian Moons Mission

Determine the nature of the surface geology and mineralogy





Characterize the regolith on Phobos/Deimos, and interpret the processes that have formed and modified it



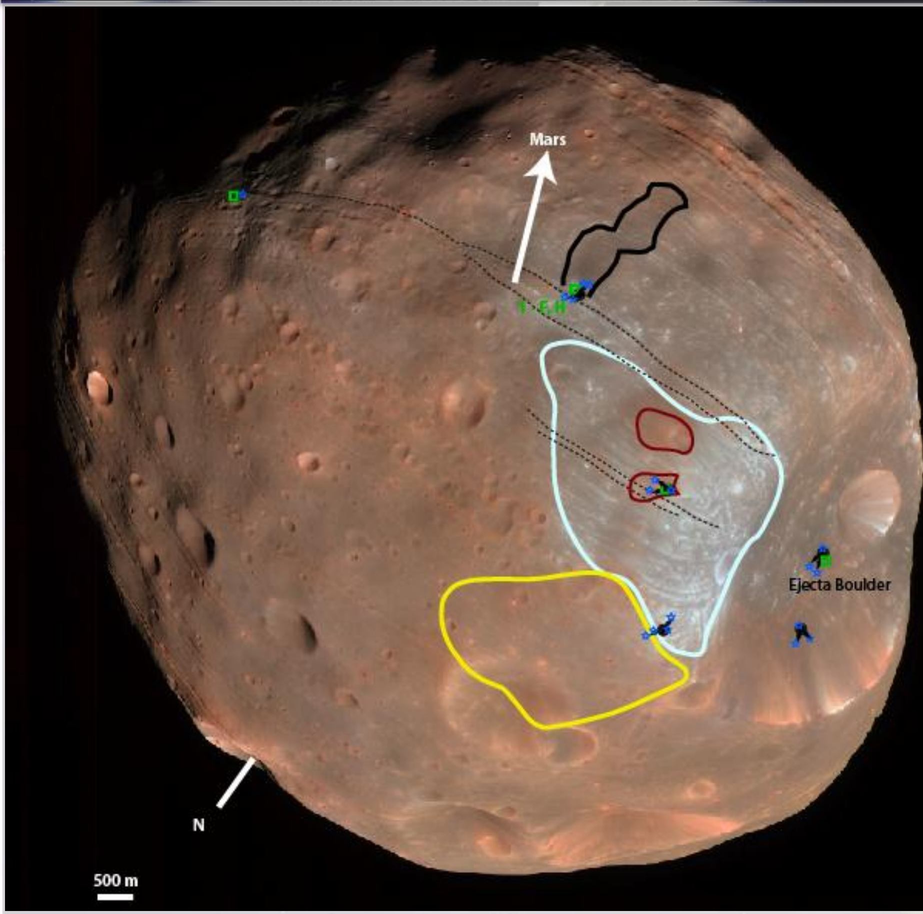
Complete the MSR Campaign by capturing and returning to Earth the orbiting cache of samples

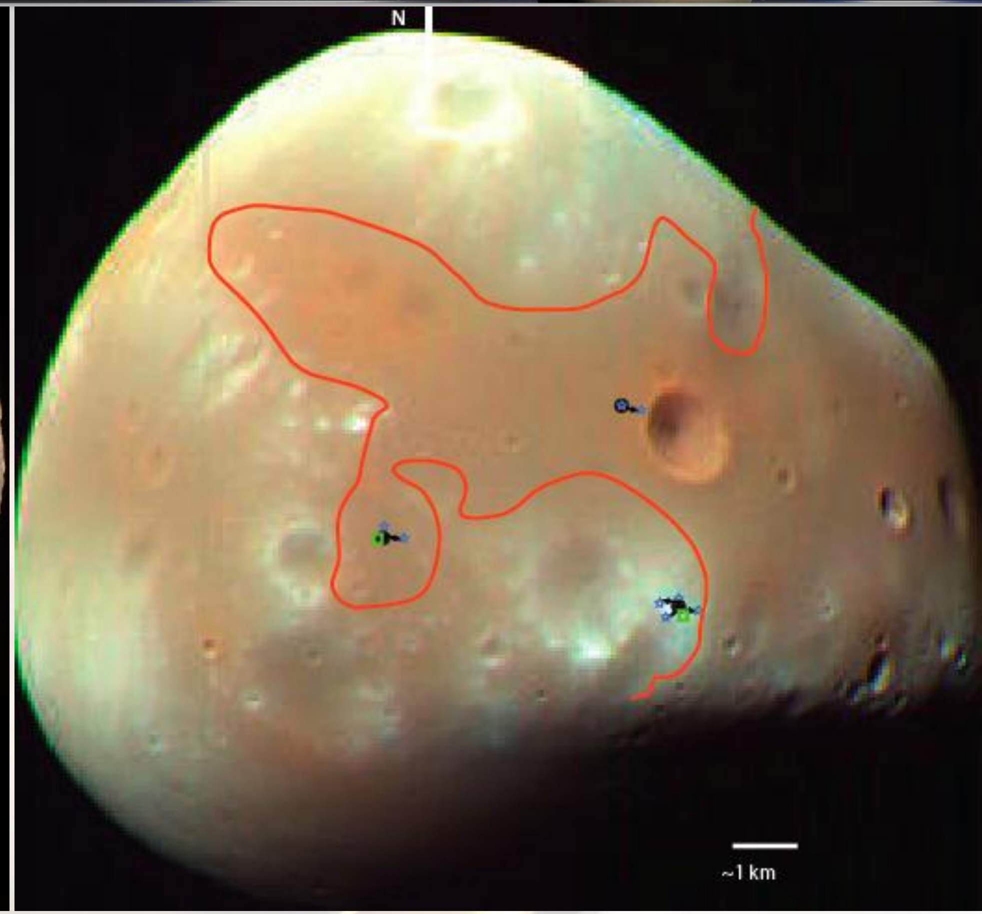
Collect Mars meteorites from the surface of Phobos/Deimos, and return to Earth for detailed study

Determine the absolute material ages and constrain the conditions of formation of Phobos and Deimos

Science at Phobos and Deimos

Reference Landing Sites





Petrological (spectral) Unit

Tectonic Feature

Landing site

Sampling site

Asset left on the surface (e.g., seismometer + heat probe, dust collector, etc.)

Note: suggested landing and sampling sites are notional – Will be refined when high-resolution mapping becomes available (precursor mission)

In-System Telerobotics

Strategy is to move some of the robotic support team in-system, achieving low-latency communications that results in more decision-points per sol.

- **Benefits**
  - Increased situational awareness, may reduce risk for more challenging operations.
  - Progress of activities can increase due to multiple decision points per sol.
  - Use of unconventional scientific platforms (e.g., airplanes and hoppers).
  - Transient science acquisition (e.g., dust devils on Mars, meteorite impact on Phobos/Deimos).

- **Challenges**
  - Much higher operations cost due to large engineering and operations support staff required for crew support.
  - In-system mission periods have limited durations, much shorter than durations available for Earth-controlled operations.
  - Time availability of in-system crew; crew has many other activities that they need to perform.
  - Additional crew training requirements for telerobotic operations.

Science and Robotics Summary

Highest-priority science objectives are based on sample return and deployment of assets, taking advantage of human crew to explore multiple sites to sample surface diversity.

Recommend visiting both Phobos and Deimos, with higher priority for Phobos, based on the current state of knowledge.

Telerobotic operations of exotic, dynamic vehicles (e.g., aerial vehicles, hoppers, climbers) on the Martian surface requires further study.

- Potential to conduct challenging operations
- Ability to move part of support team in-system to achieve low-latency communications resulting in more decision-points per sol

Many opportunities exist for transit science that are diverse and provide opportunities for public engagement and crew involvement during long transits.

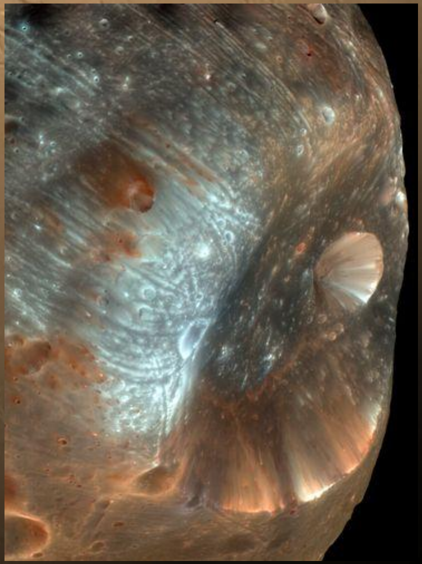
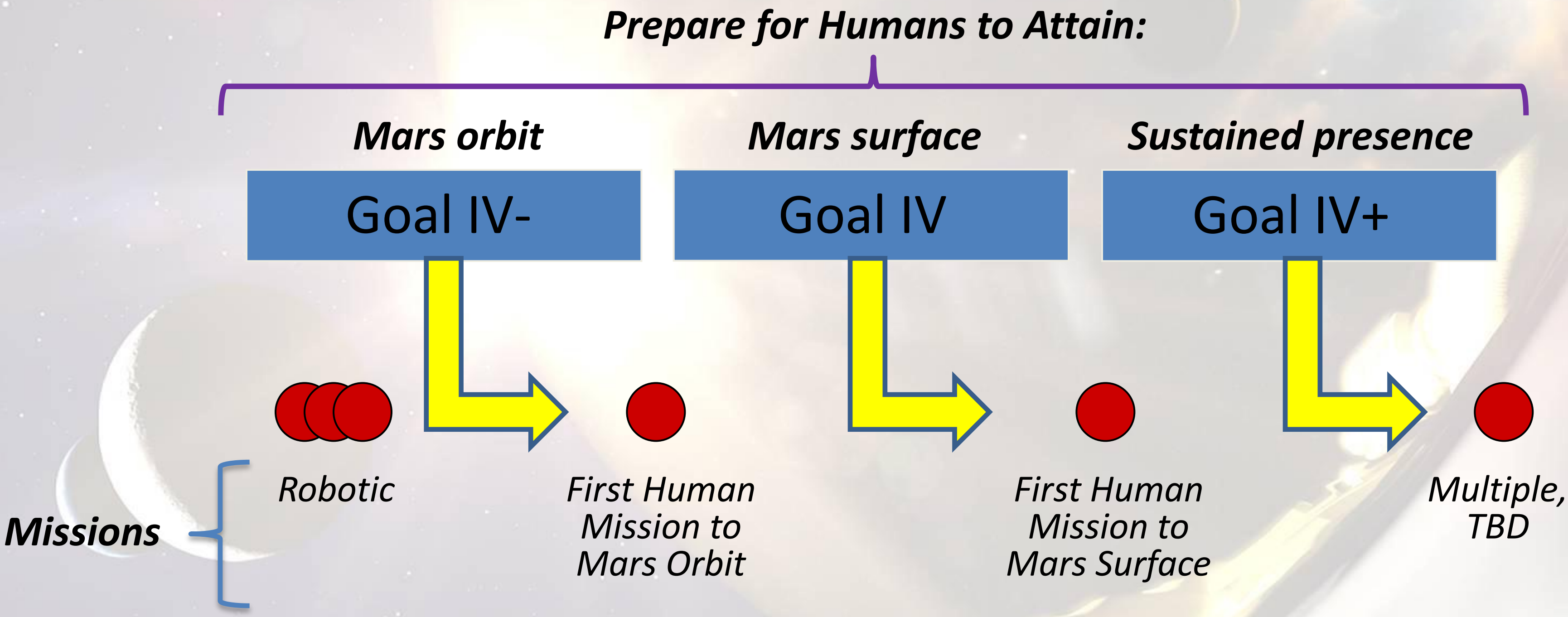


Image Credit: NASA/JPL-Caltech

Image Credits: NASA/AMA, Inc.

Human Exploration Goals in an MPD Mission

- **A human MPD mission will be part of a larger campaign of human exploration of Mars, including its surface, its moons, and the surrounding environment.**



- **"Human Exploration Goals and Objectives" encompass gathering data and demonstrating technologies/operations needed in advance of humans attaining the next level of Mars exploration.**

Human Exploration Objectives for Mars Missions (including MPD)

1. Obtain knowledge of Mars, its moons, and the surrounding environment sufficient to design and implement human missions with acceptable cost, risk, and performance.
2. Conduct technology, operations, and infrastructure demonstrations in transit to, in orbit around, or on the surface of Mars or Phobos and Deimos to reduce risk or cost for human missions.
3. Incorporate partnerships (international, commercial, etc.) that broadens overall organizational participation but also lowers the total program cost for each partner.
4. Incorporate multiple public engagement events spread across entire mission durations and using multiple media types.
5. Prepare for sustained human presence.

- Applications of teleoperations at Mars that will satisfy human exploration objectives are unclear at this time and require further study.

High-Level Concept of Operations

Activity	Days	Total
Arrival Operations	2	2
SEVs Transfer to Phobos	2	4
Phobos Locations 1 & 2	8	12
Phobos Locations 4 & 6	8	20
Phobos Locations 3 & 5	8	28
SEVs Transfer to Mothership	2	30
At Mothership	3	33
SEVs Transfer to Deimos	3	36
Deimos Sites 1 & 3	7	43
Deimos Location 2 & TOA	5	48
SEVs Transfer to Mothership	3	51
Departure Operations	2	53
Contingency	3	56

Location	Days
At Mothership	10
Transfer	10
At Phobos	24
At Deimos	12

Concept is a conservative, existence proof.

Attempts were not made to optimize the concept.

Strategic Knowledge Gaps (SKGs): Humans to Mars Orbit Only

Strategic Knowledge Gap	Human Mission Relevant Measurements	Priority
Atmosphere properties related to aerobraking	Temperature, winds, aerosol abundance and profile; global and diurnal coverage	Medium-High ?
Particulate environment	Spatial variation in size-frequency distribution of Phobos/Deimos ejecta particles in Mars orbit	Medium

DISCUSSION

- **Mars Orbit Insertion (MOI).** Since aerocapture may or may not be pursued for orbital missions, it should be assumed that it might and therefore what knowledge would be required should be determined . It may be possible to develop aerobraking much earlier with more knowledge.

- **Debris.** Orbital particulate environment potentially more significant in high Mars orbit (near Phobos/Deimos and in the equatorial plane) than in low Mars orbit.

Strategic Knowledge Gaps (SKGs): Visit Mars Orbit and Phobos/Deimos Surface

Mars Orbit SKGs, PLUS:

Strategic Knowledge Gap	Human Mission Relevant Measurements	Priority
Mineralogical & chemical composition	Elemental / chemical composition; spatial distribution of major geologic units; ISRU potential	High
Regolith mechanical & geotechnical properties	Size-frequency distribution; density, compressibility, adhesion; spatial variation in thickness/properties	High
Gravitational field	Spherical harmonic terms of moons' gravitational fields	Medium
Electrostatic charging & plasma fields	Electric fields in proximity to surface, plasma emanating from surface	Low
Thermal environment	Temperature variation diurnally, with depth	Low

DISCUSSION

- **Mineralogy et al.** Mineralogy/chemistry needed to support productive science operations; may also influence operations planning.
- **Regolith.** Regolith contact measurement and mapping needed for ops planning and surface interaction considerations.

Strategic Knowledge Gaps (SKGs):
Visit Mars Orbit and Phobos/Deimos Surface (cont.)

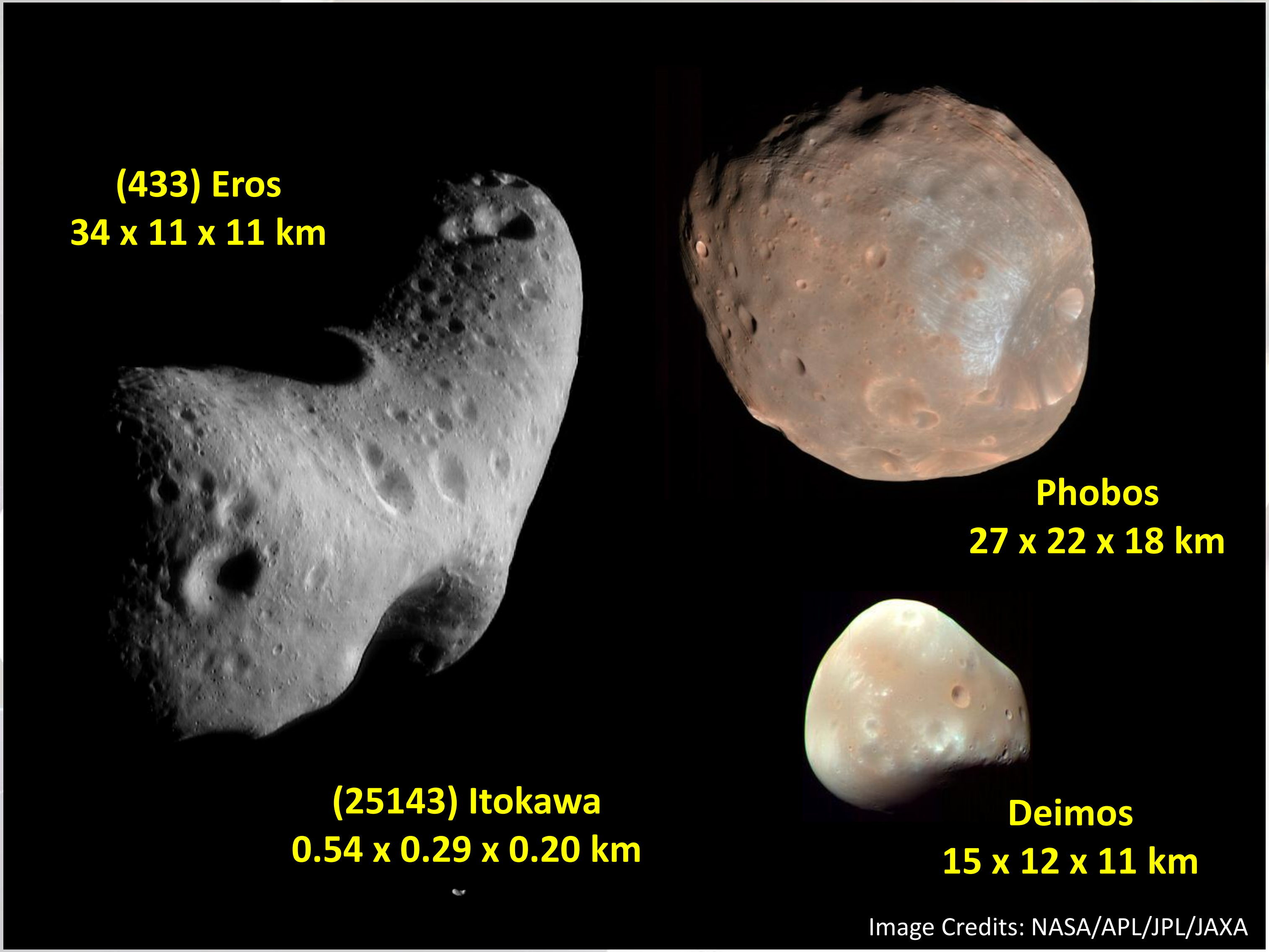
DISCUSSION

- **Gravity.** Gravitational field measurements recommended for planning proximity operations, including station keeping modes.
- **Electrostatics.** Electrostatic charging and plasma environment influences engineering of surface elements and EVA equipment designs.
- **Thermal.** Thermal environmental conditions vary significantly over diurnal time scales and regolith depth. Data informs what would be adequate engineering of surface elements, including EVA equipment designs.

STILL UNDER DEBATE

- **Radiation.** Require(?) better understanding of interaction with Phobos/Deimos for shielding/secondary effects. The SKG relates to tissue equivalent response, not to basic measurement of galactic cosmic radiation (GCR) and solar particle event (SPE).

NEAs at Approximate Scale with Martian Moons



Synergies of NEAs for Missions to Phobos and Deimos

Robotic Precursor Activities

- Enable target identification and selection for future human mission activities.
- Constrain internal and near-surface structure on regional and global scales.
- Characterize basic physical properties relevant for future human safety, performance, and operations.

Human Exploration/Operations

- Lessons learned from building reliable power, propulsion, communication, and life support systems for long duration (> 30 days) missions.
- Understand how to operate in close proximity to, and at the surface, of a non-cooperative object in a low gravity regime.

Small Body Science

- Small bodies are the left over primitive materials from the earliest stages of Solar System formation (e.g., potential Phobos/Deimos asteroid connections).
- *In situ* science combined with sample return enables better understanding of these bodies' origin/dynamical history, nature of their material composition, thermal properties, oxidation state, and collisional histories.

Synergies of NEAs for Missions to Phobos and Deimos

Resource Utilization

- Perform extraction demonstration of small token quantities as a proof of concept (i.e., extraction of volatiles from NEA or Phobos/Deimos materials).
- Evaluate the utilization of resources for life support, propulsion, and other potential applications to enhance safety and efficacy of human spaceflight.

Human Factors

- Measure effects of communication delays/blackouts and impact to crew morale/performance.
- Characterize synergistic effects of radiation, microgravity, crew confinement, on human immune system during extended duration deep space voyages.
- Monitor psychological effects of living in deep space for extended periods of time with no rapid return possibilities.

Transit Science

- Evaluate multiple opportunities for science to be conducted en route to and from primary target (e.g., planetary, life science, astrophysics, heliophysics).

MPD Cis-Lunar Synergies Priorities

(Lower priorities are rest of activities in more detailed presentation)

Synergy Activity	Priority
HUMAN RESEARCH: all activities (except artificial gravity)	High
TELEROBOTICS	
Simulate delays and different orbital operational implications for Mars surface	High
Conduct "fast" traverses to assess potential science return (could help with diversity)	High
Assess real-time science responsiveness	High
Perform analog tests for telerobotic operations of MPD surfaces – Relates to proximity operations synergy	High*
Conduct public outreach activities	Med
MISSION SYSTEM AND SUPPORT	
Radiation shielding	High
Life support system reliability	High
Medical support: health monitoring/treatment, including for planetary protection purposes	High
Subsystem serviceability and sparing	Med
Test pre-deploy strategies - e.g., consumables, fuel, and Automated Rendezvous and Docking (AR&D)	Med
LONG-TERM DEEP SPACE HUMAN OPERATIONS	
Crew autonomy / control authority tests	High
Verify & mature long-duration crew medical care operations	High
PROXIMITY OPERATIONS: Crew translation, restraint, worksite stabilization (build crude analog)	Med
SAMPLE RETURN: Return samples from lunar orbit/surface to cis-lunar asset as analog to returning samples from Martian orbit/surface to return vehicle	Med

* An effective precursor mission could substantially reduce (but not eliminate) the dependency on telerobotic surface interaction.

MPD Cis-Lunar Synergies Summary

- There are a number of promising activities to conduct in cis-lunar space to help prepare for a human MPD mission.
- Most human research needed for a MPD mission can be conducted during cis-lunar missions.
- Crew autonomy is a key area to test during cis-lunar missions.
- Telerobotics has high potential, but also high uncertainty for science effectiveness and requires additional analysis and testing.
- Large amounts of sample, that may not be returned directly to Earth, could be received at a cis-lunar facility.

Precursor and Destination Synergy Summary

Robotic precursor to Phobos and Deimos could provide significant risk reduction by addressing strategic knowledge gaps early enough to inform human mission design.

Key synergies exist to leverage human missions to cis-lunar destinations and NEAs, including:

- Human research and gaining deep-space operations, systems reliability, logistics and maintenance experience
- Proximity ops, surface interaction, and in-situ resource utilization
- Robotic precursors, small body science, sample return, and transit science

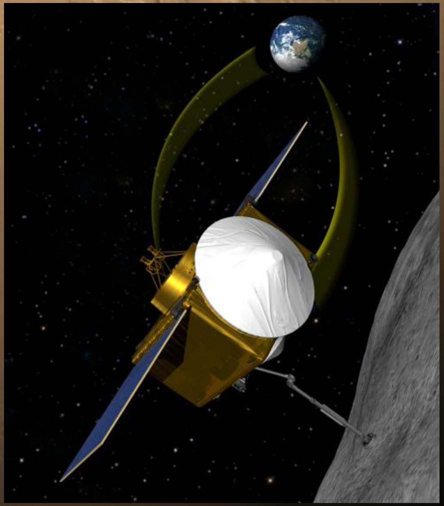


Image Credit: NASA/GSFC/U. of Arizona

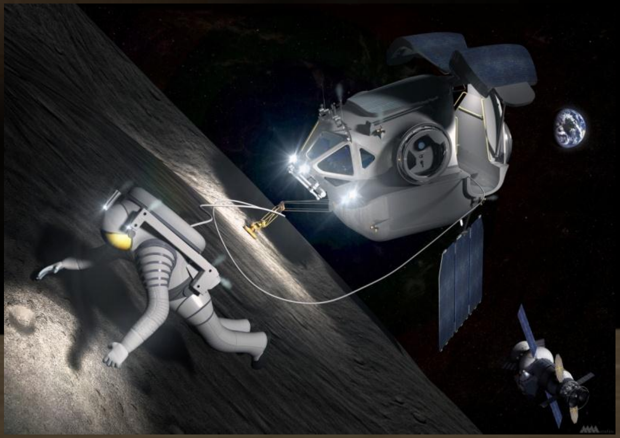


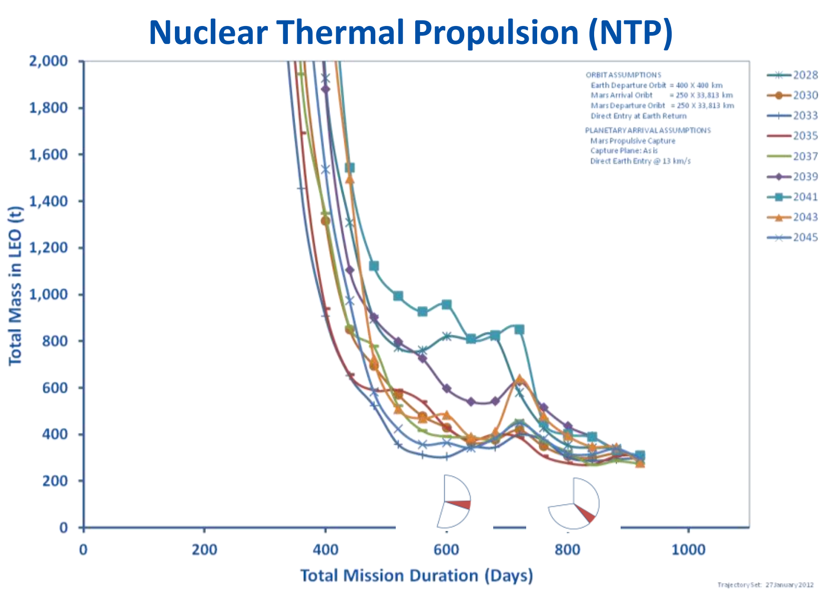
Image Credit: NASA/AMA, Inc.

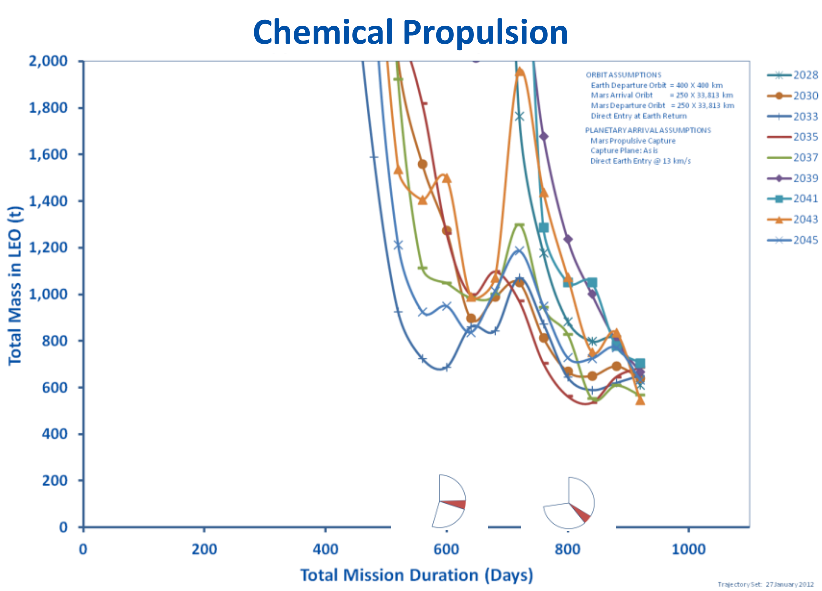
Human Martian Moons Exploration Summary

Human exploration goals and objectives encompass gathering data and conducting technology, operations, and infrastructure demonstrations needed in advance of humans attaining the next level of Mars exploration (Mars surface and sustained presence).

Preliminary estimates of the expected Initial Mass in Low-Earth Orbit (IMLEO) of a transportation architecture using NTP for a 550-day opposition-class mission range from 350-1000+ tons (opportunity dependent). Additional IMLEO is required for destination systems.

- Long-stay (conjunction-class) missions offer the advantage of lower overall mission mass (due to lower total ΔVs) and longer time in the Mars system for exploration activities, but with a longer overall mission time.
- Additional factors (e.g., cost, risk, mission operations, and value of additional science/exploration time) must be taken into account before reaching a conclusion on the most appropriate mission mode to achieve mission objectives.





Preliminary Finding

An opposition-class (short-stay) Phobos/Deimos mission appears *<u>feasible</u>* from a destination operations standpoint.

- All currently identified science and exploration objectives accomplished in 56 days.
- Ample margin and mission reduction opportunities provide confidence that a worthwhile mission could be completed within 60-90 days.

(both moons to the same scale)

Image Credits: NASA/JPL-Caltech/University of Arizona

Closing Comments

- **The Mars-Phobos-Deimos study effort provided valuable inputs for the possible establishment of a Design Reference Mission (DRM) and understanding the synergistic activities required prior to undertaking such a human exploration endeavor**
- **Duration/scope of study did not allow the MPD team to fully address or resolve various aspects of MPD mission design. For example:**
  - In-depth investigation of Mars sample return retrieval by crew
  - Detailed mission operations and EVA trade studies
  - Derive destination activity payload masses and aggregate to determine outbound and inbound mission requirements
  - Cost-risk-benefit analysis to permit selection of mission mode and options to achieve mission objectives
- **Future mission designs should also investigate innovative approaches and technologies to show their benefits along with their risks. For example:**
  - Use of aerocapture for human mission segment
  - In-situ resource utilization of materials from Phobos and/or Deimos (propellant, radiation shielding, etc.) and use of moons as a staging locations for Mars surface mission

Why We Explore

"Our only chance of long-term survival is not to remain lurking on planet Earth, but to spread out into space."

– Stephen Hawking
Theoretical physicist & cosmologist

“People want me to tell you. ‘Well, what are you going to find?’ Whatever. ‘Well, that’s just not good enough.’ What do you mean that’s not good enough? ‘Look, you don’t know what you’re gonna find?’ If I did, I wouldn’t be going!”

– Dr. Robert Ballard
Oceanographer & discover of the RMS Titantic & Lusitania, Bismark, and USS Yorktown

Thank you for your time and attention.