National Aeronautics and Space Administration

Mars as a Destination in a Capability-Driven Framework

ASCE Earth and Space 2012 Conference

Pasadena, California

Stephen J. Hoffman
Bret G. Drake
John D. Baker
Stephen A. Voels

18 April 2012

Mars Mission Modes

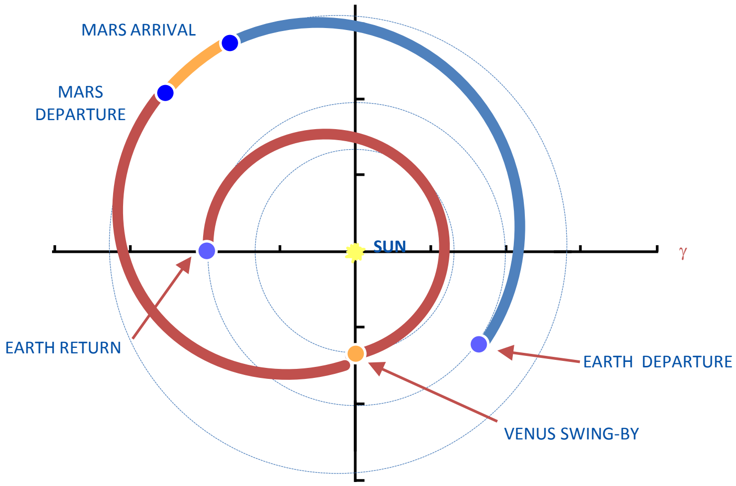
- **Round-trip human missions to Mars are double rendezvous problems**
  - Relative phasing of Earth-Mars (outbound leg) must be considered along with the relative phasing Mars-Earth (return leg)
- **This leads to two distinct mission classes**

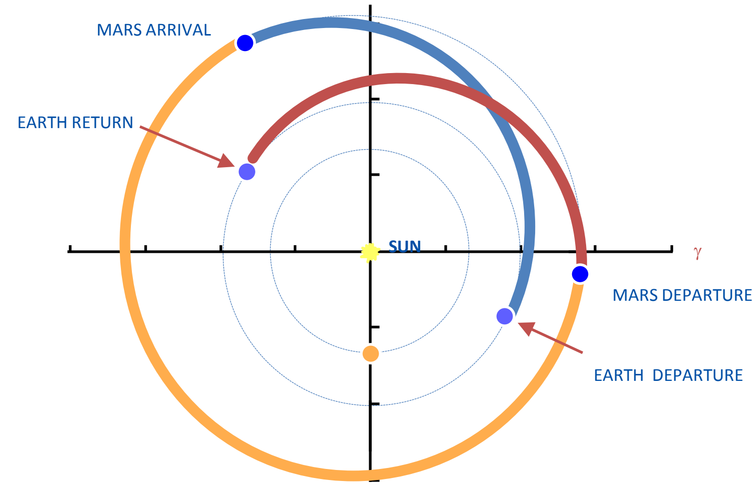
Short-Stay (Opposition Class)

- Variations of missions with short Mars surface stays and may include Venus swing-by
- Often referred to as Opposition Class missions

Long-Stay (Conjunction Class)

- Variations about the minimum energy mission
- Often referred to as Conjunction Class missions



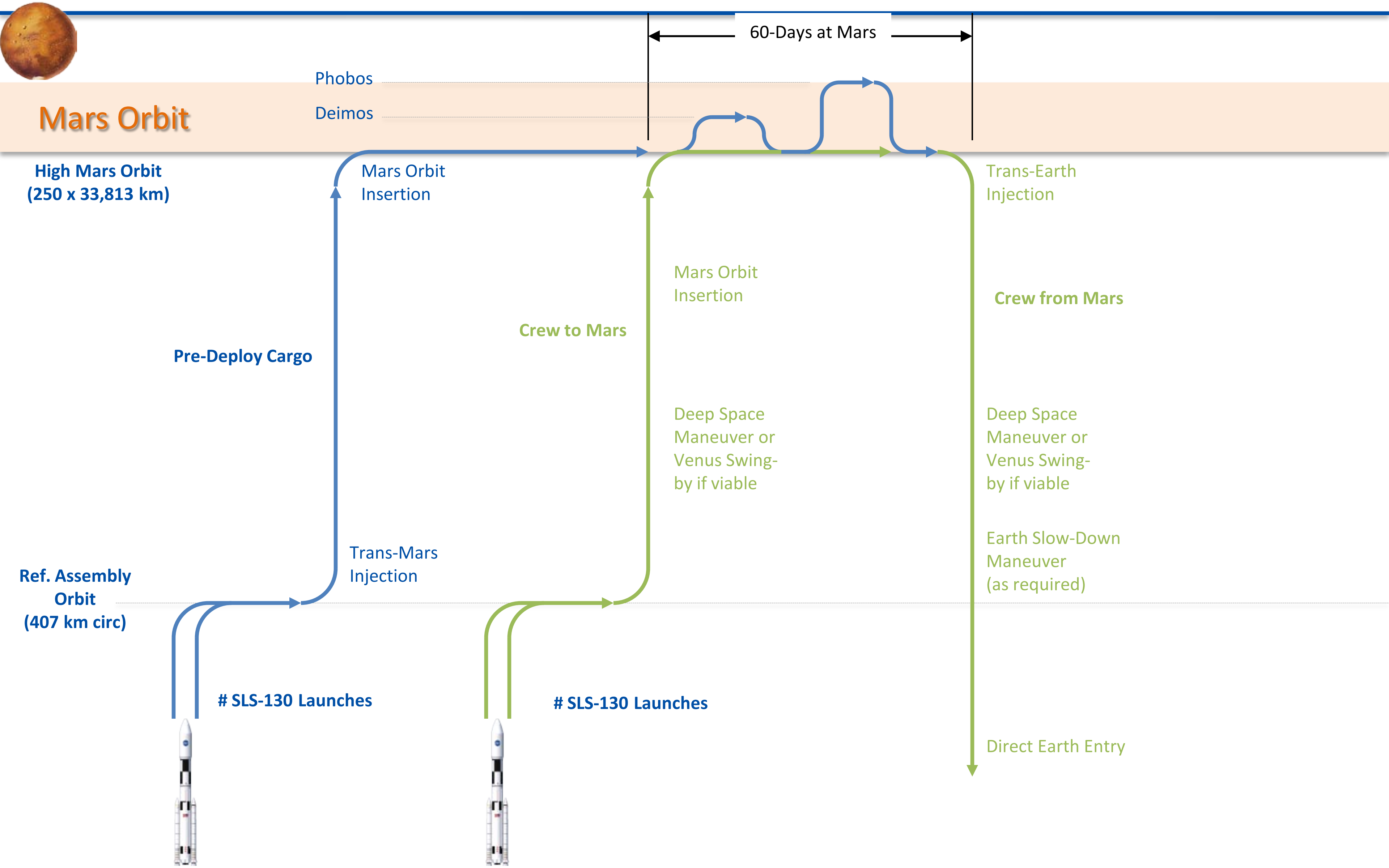


MARS ORBITAL MISSIONS

Exploration of Phobos and Deimos

Short Stay Orbital Design Reference Mission

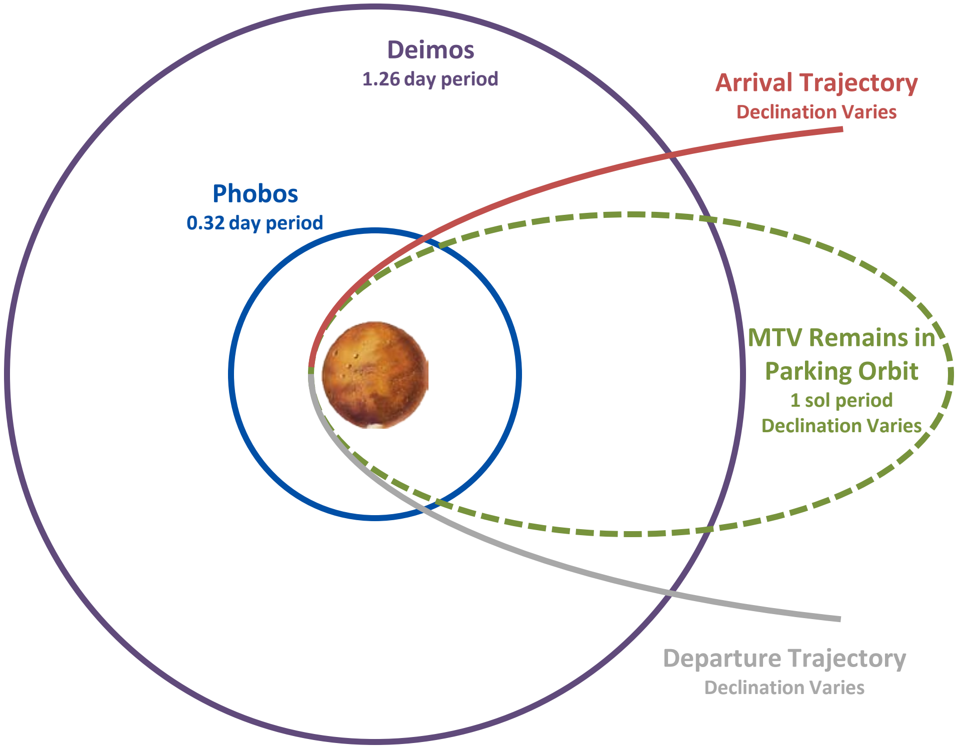
High Thrust Missions



Human Spaceflight Architecture Team

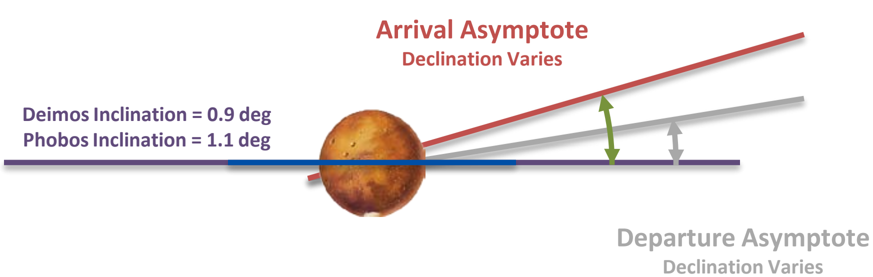
Short Stay Orbital Operations Concept

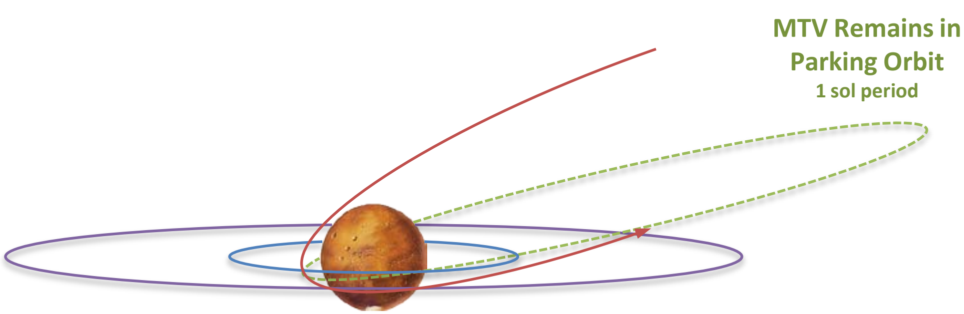
High Thrust Missions



Assumed Mars Orbit Strategy

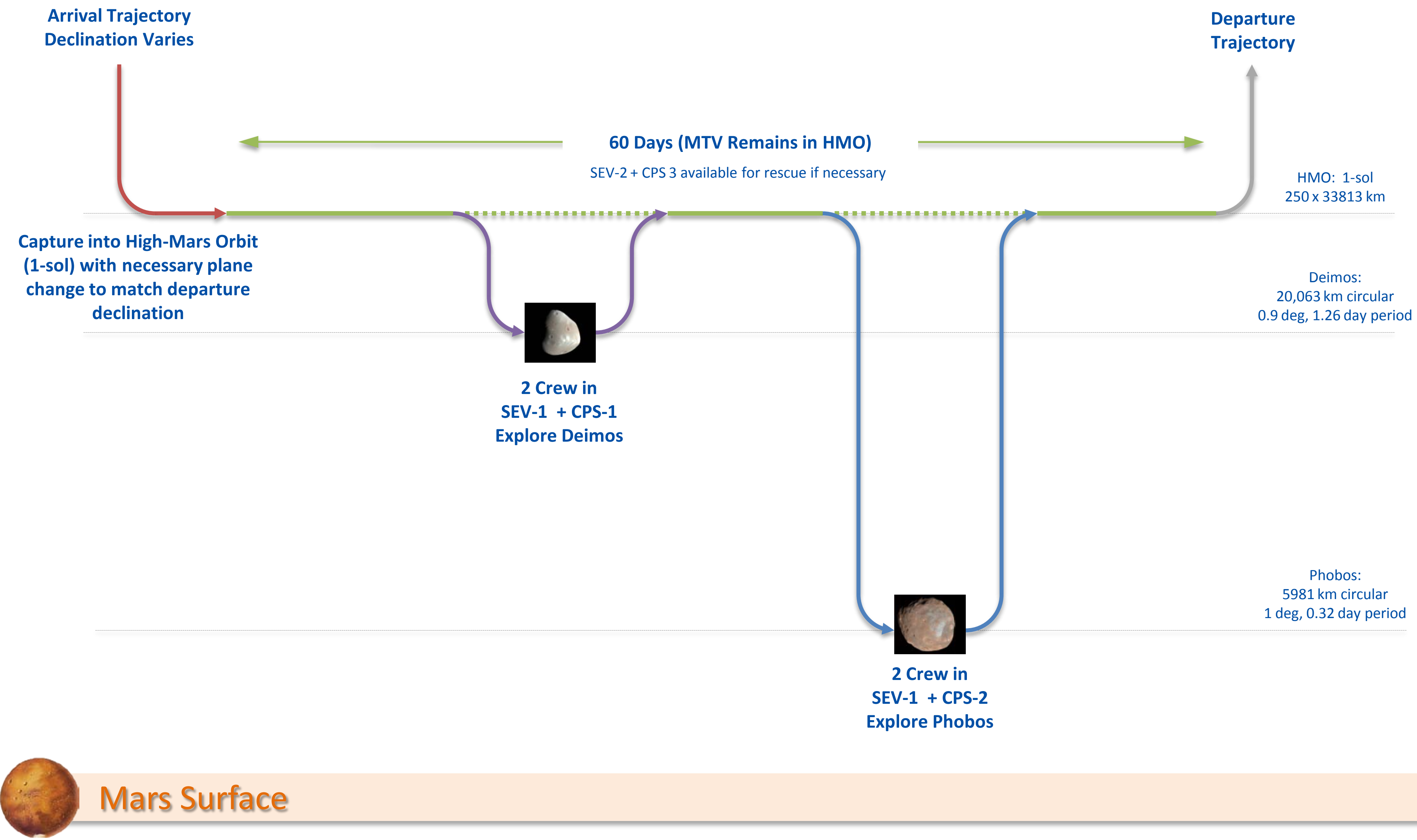
1. Capture into a 1-sol parking orbit (250 x 33,813 km) with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,300-1,600 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for 14 days (1,630-2,000 m/s delta-v required)
6. Prepare for Mars departure
7. Trans-Earth Injection





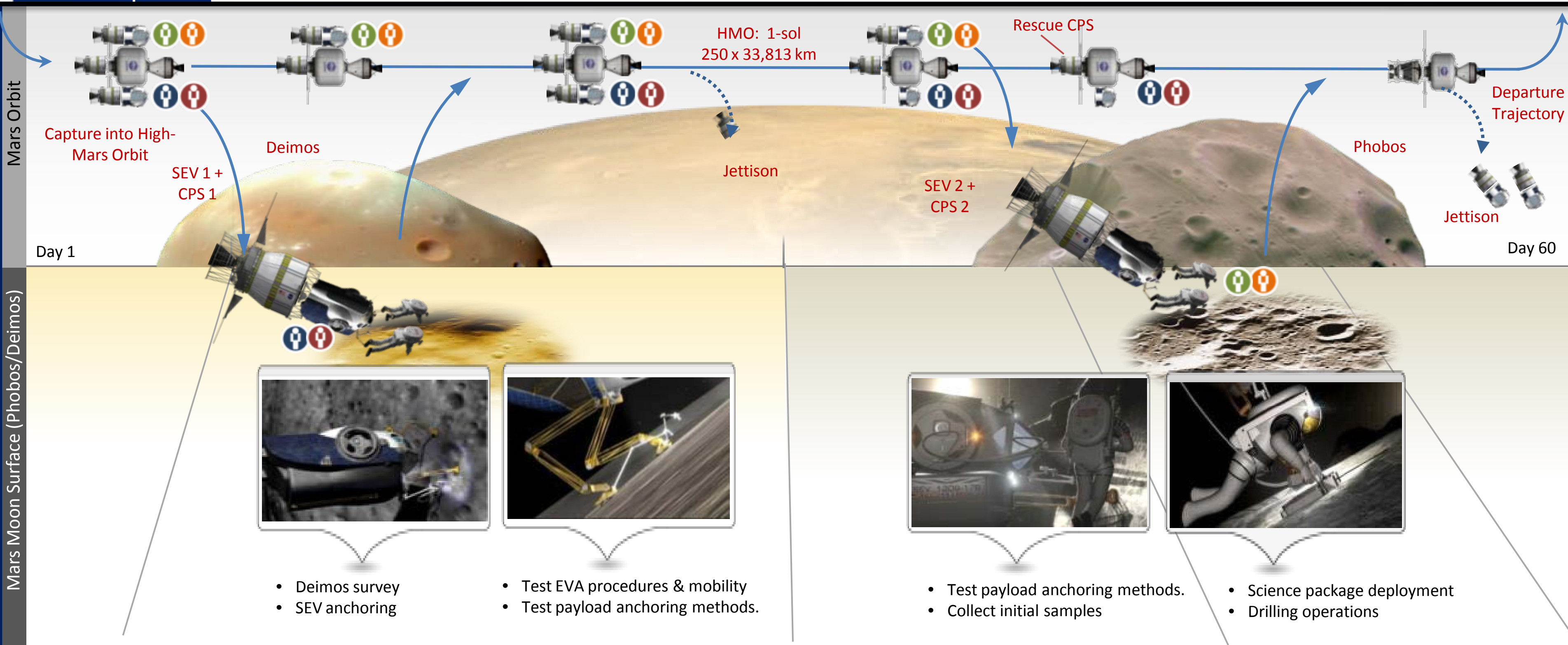
Short Stay Mars Orbital Operations

High Thrust Missions



Short Stay Mars Orbital Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

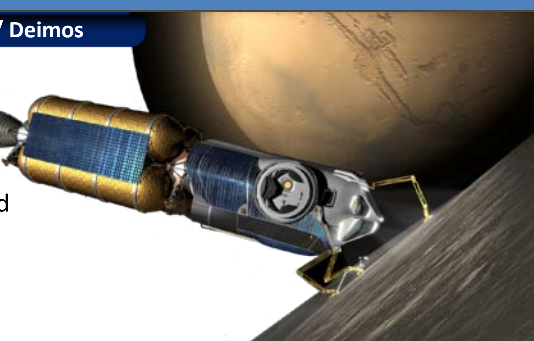
1. Capture into a 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos for 14 days (1,370-2,770 m/s delta-v required)
5. Utilize SEV-2 to explore Phobos for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

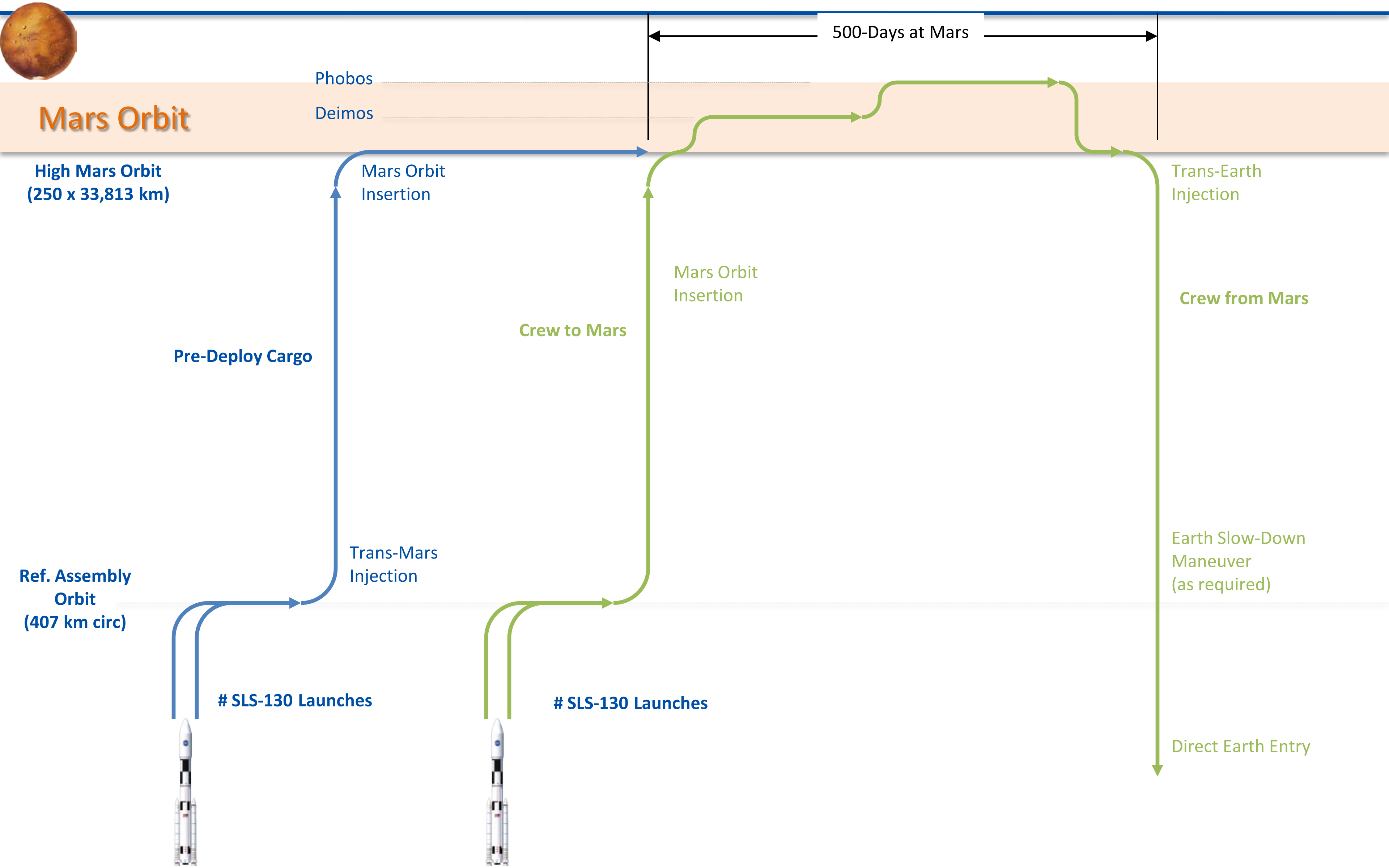
Deimos:
20,063 km circular
0.9 deg, 1.26 day period

Phobos:
5981 km circular
1 deg, 0.32 day period



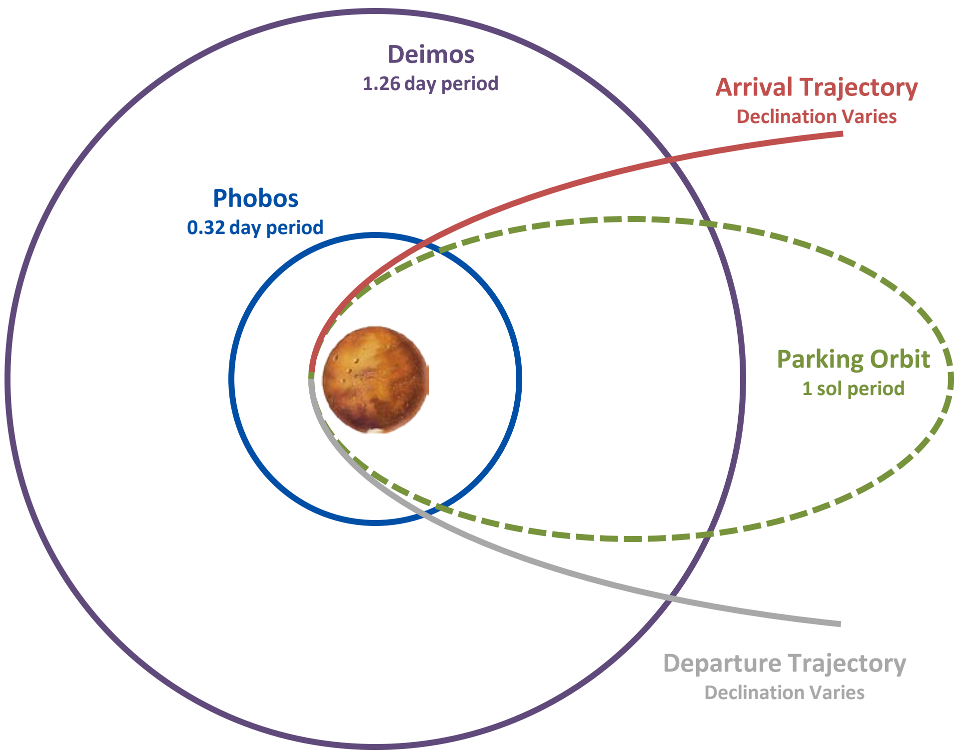
Long Stay Orbital Design Reference Mission

High Thrust Missions



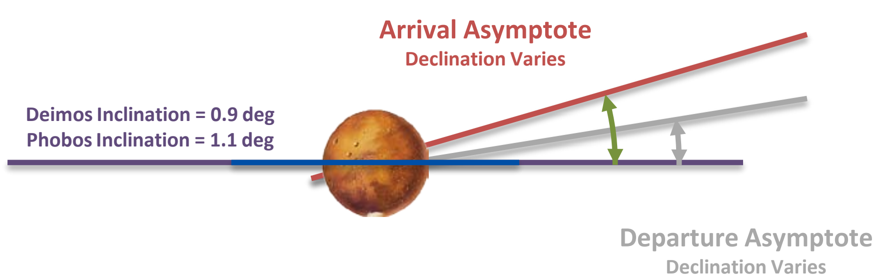
Long Stay Orbital Operations Concept

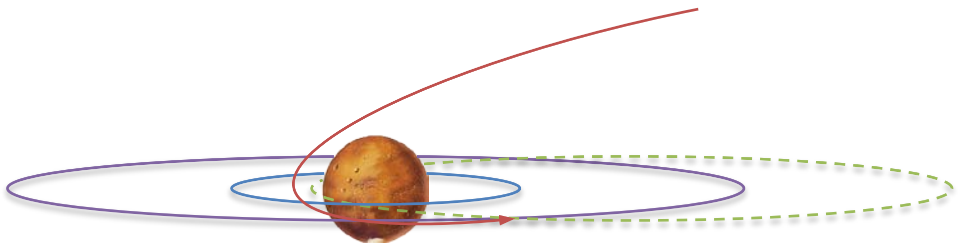
High Thrust Missions



Assumed Mars Orbit Strategy

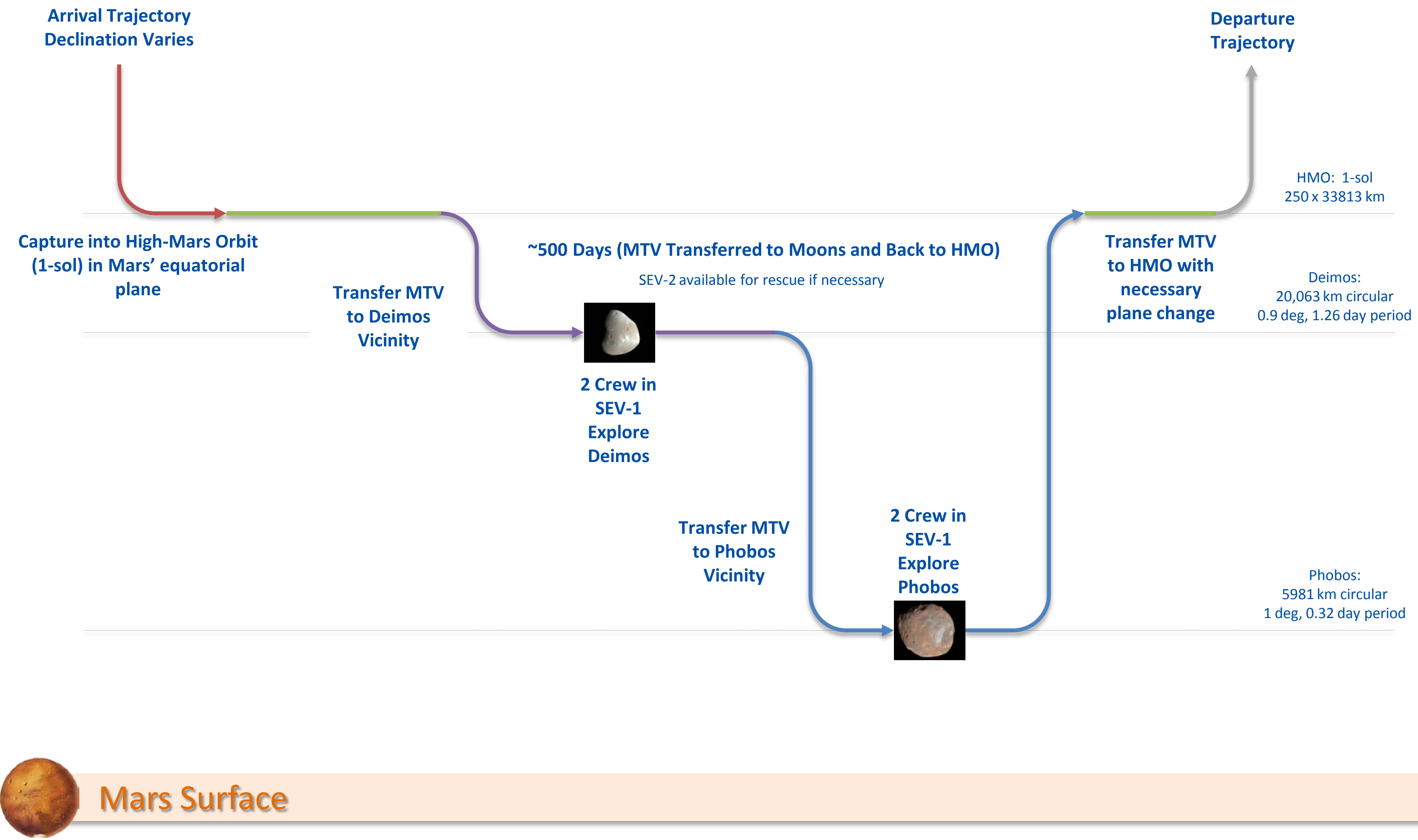
1. Capture into a 1-sol parking orbit (250 x 33,813 km) with proper plane change to Diemos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (653 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit (784 m/s delta-v required)
6. Utilize SEV-2 to explore Phobos numerous times
7. Prepare for Mars departure including orbit and plane change
8. Trans-Earth Injection





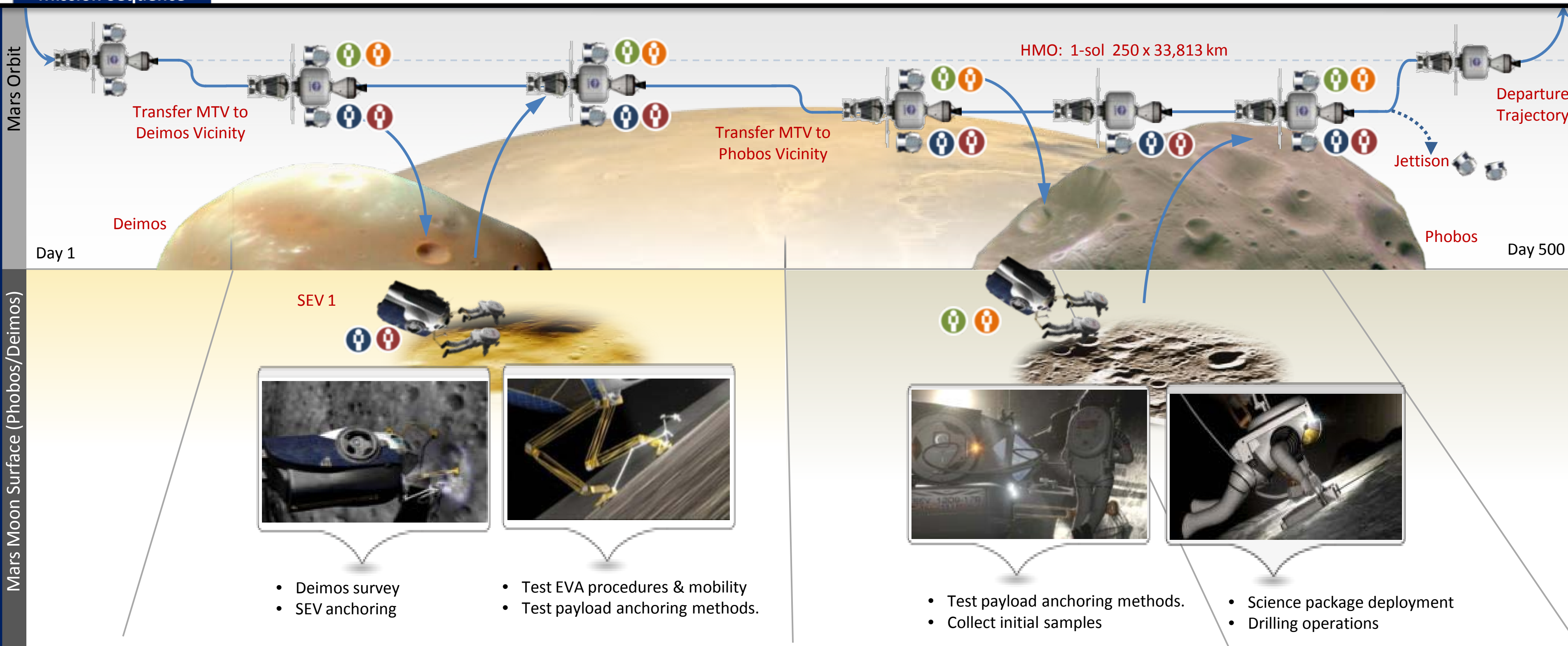
Long Stay Mars Orbital Operations

High Thrust Missions



Long Stay Mars Orbital Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

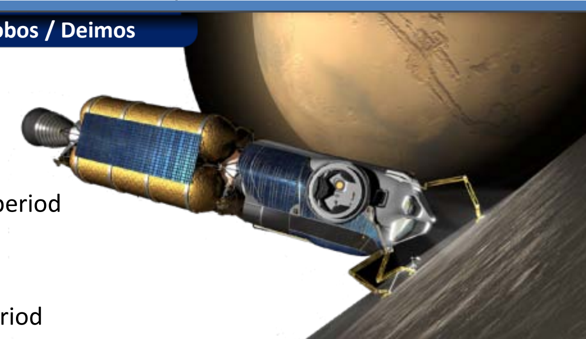
1. Capture into a 1-sol parking orbit with proper plane change to Deimos inclination
2. Lower Mars Transfer Vehicle to Deimos orbit (767 m/s delta-v required)
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Deimos numerous times
5. Lower Mars Transfer Vehicle to Phobos orbit (816 m/s delta-v 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, 1.26 day period

Phobos:
5981 km circular
1 deg, 0.32 day period

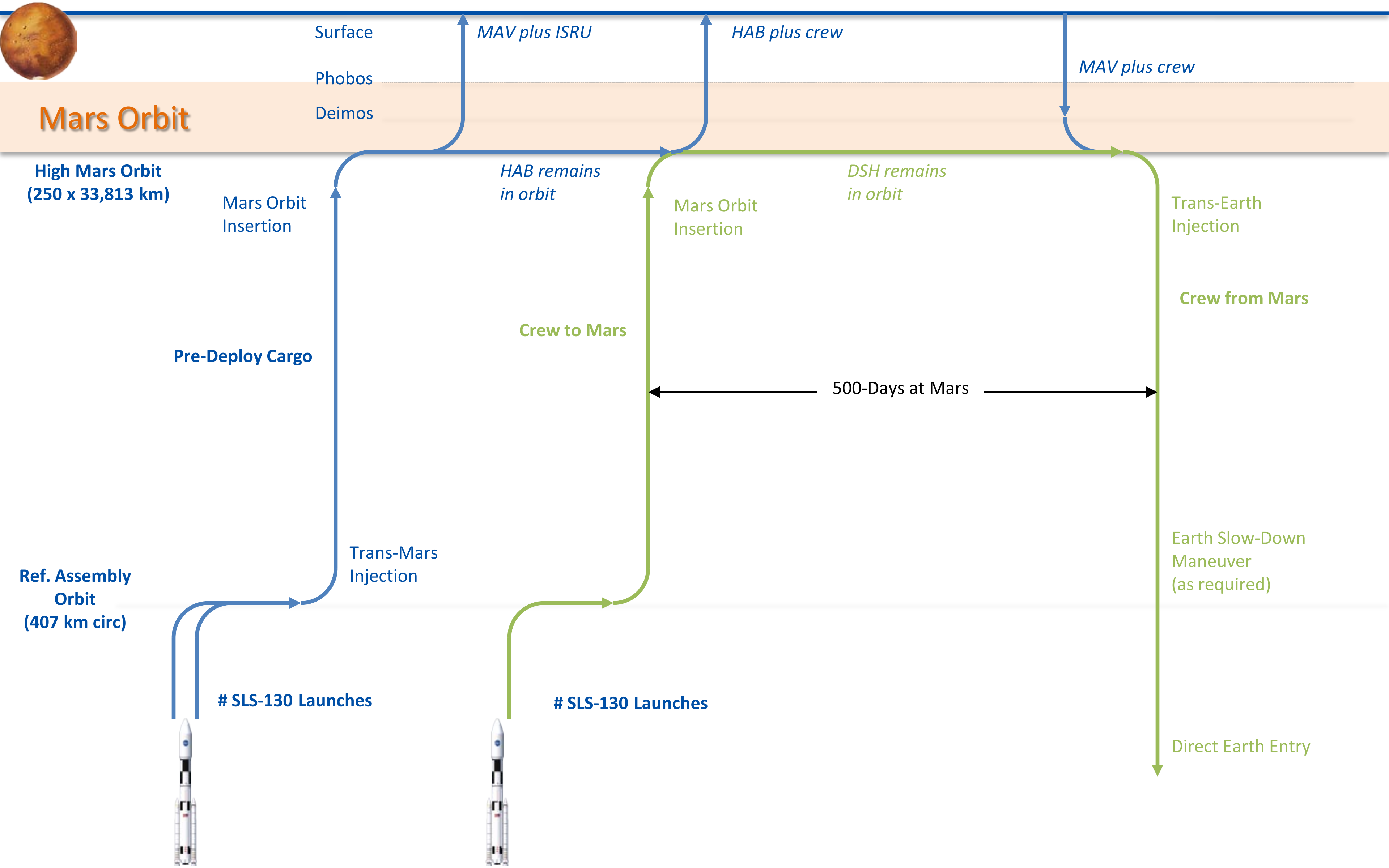


MARS SURFACE MISSIONS

Exploration of the Surface of Mars

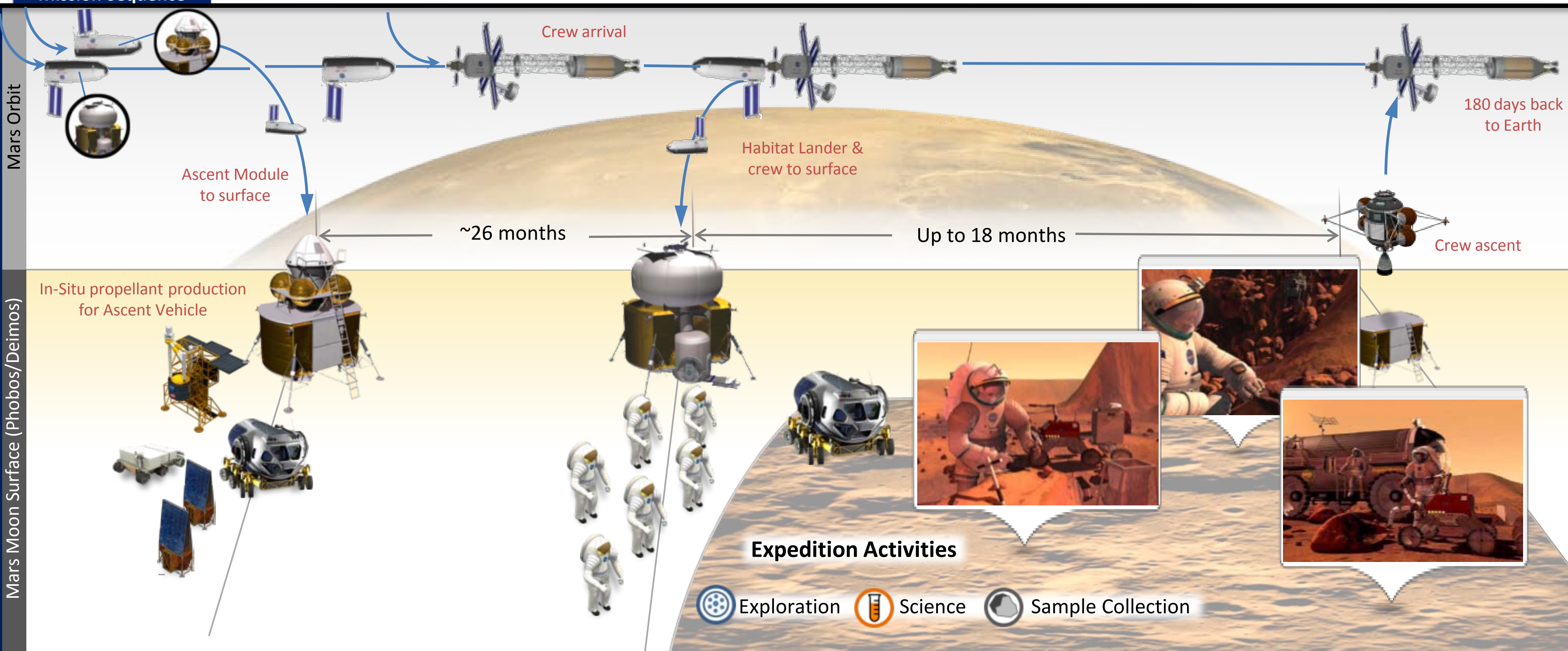
Long Stay Surface Design Reference Mission

High Thrust Missions



Mars Surface Operations

Mission Sequence

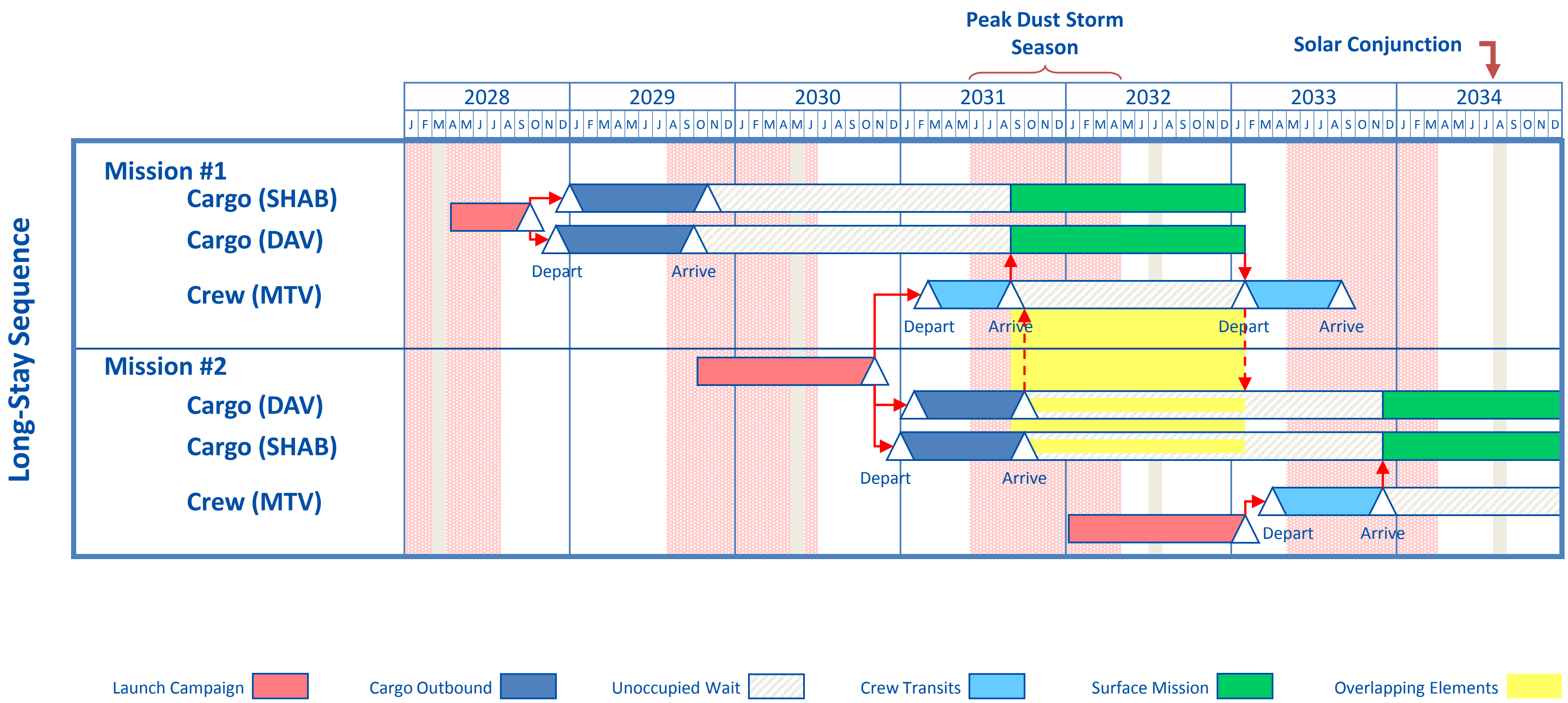


Mission Summary

- Long surface stays with visits to multiple sites provides scientific diversity
- Sustainability objectives favor return missions to a single site (objectives lend themselves best to repeated visits to a specific site on Mars)
- Mobility at great distances (100’s km) from the landing site enhances science return (diversity)
- Subsurface access of 100’s m or more highly desired
- Advanced laboratory and sample assessment capabilities necessary for high-grading samples for return

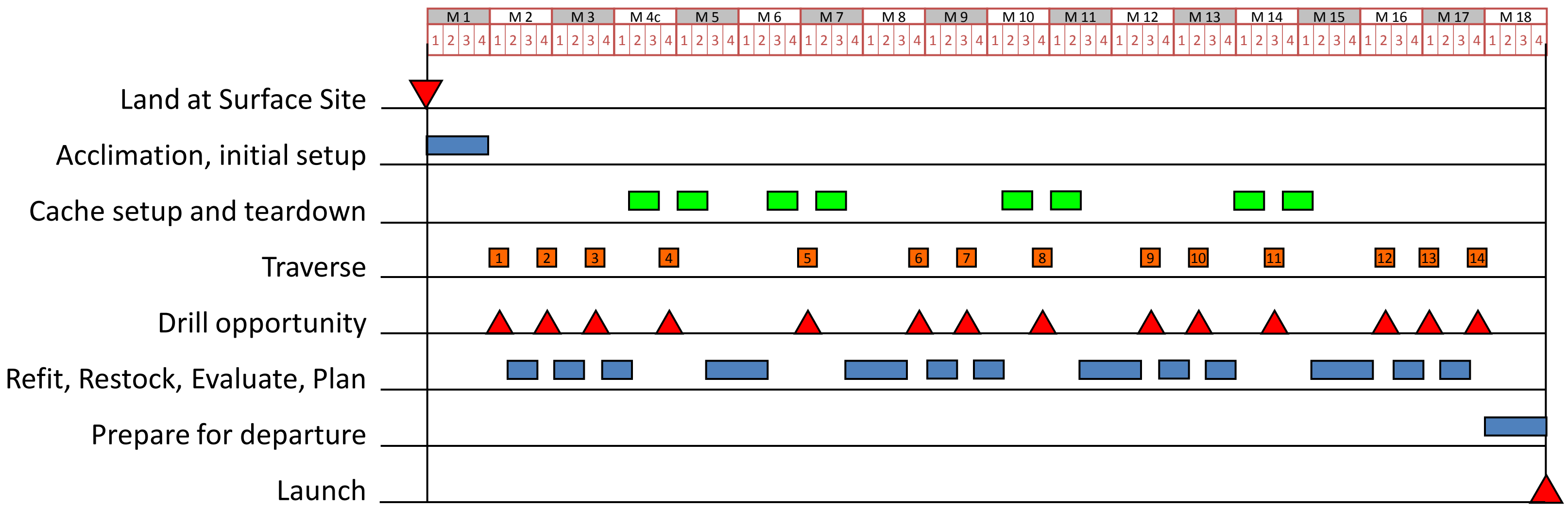
Mission Site: Mars Surface

Long Stay Mars Surface Mission Sequence Pre-Deploy Option



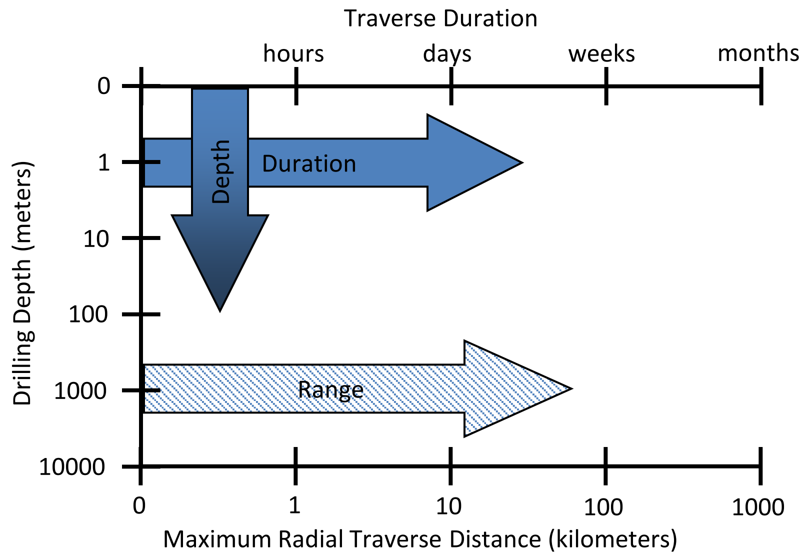
Surface Mission ConOps Option 2: “Commuter”

Notional Surface Mission Activities



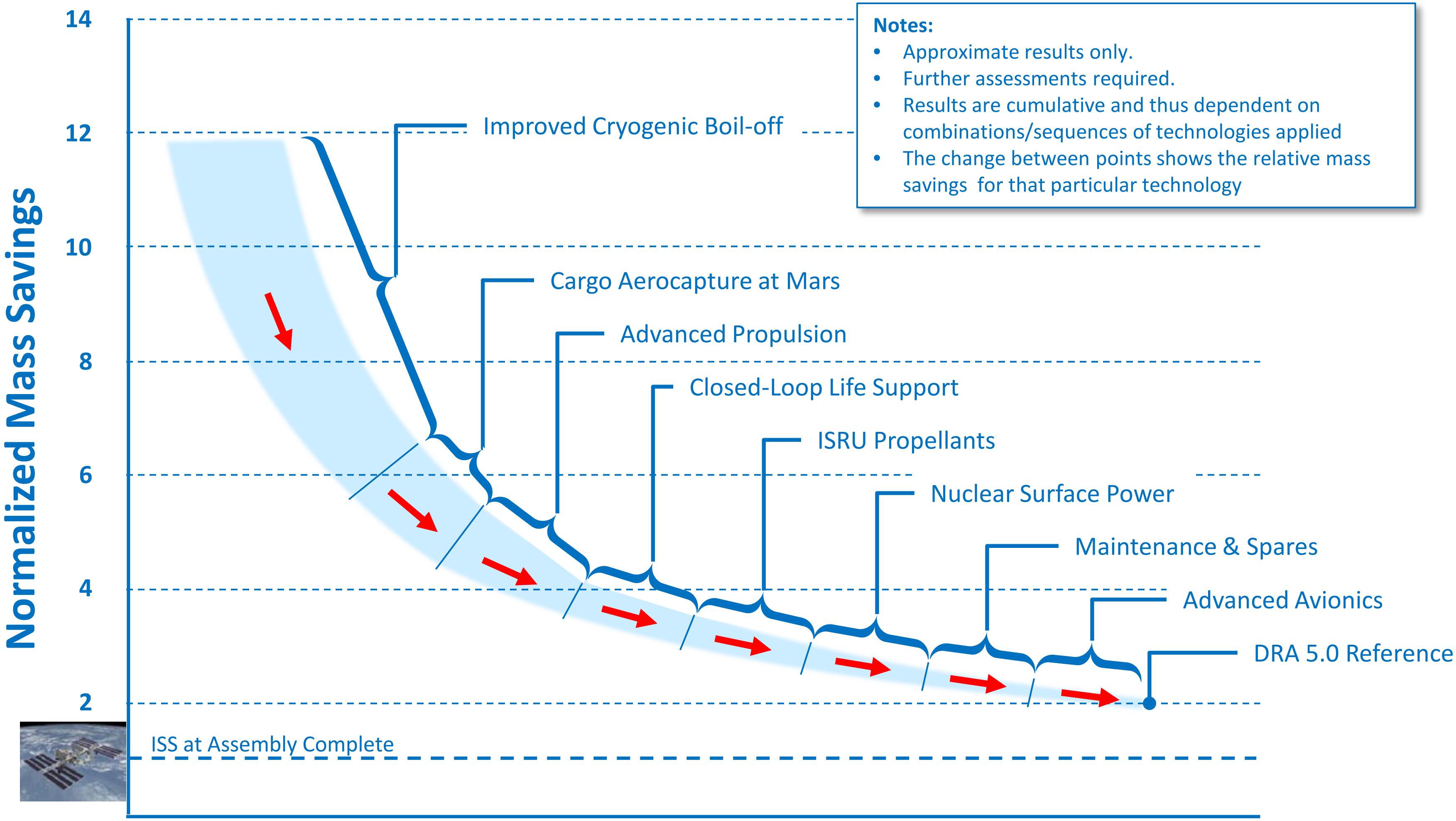
Surface Assets

Item	Mass
Primary Habitat	15 MT (est)
Sm. Press. Rover x 2	6 MT (est)
Crew Consumables	7.5 MT (est)
Drill	1 MT (est)
Science Equipment	1 MT (allocation)
ISRU and Power Plant	2 MT (est)
Robotic Rovers x 2	0.5 MT (allocation)
Total	33 MT



The Value of Technology Investments
Mars Mission Example

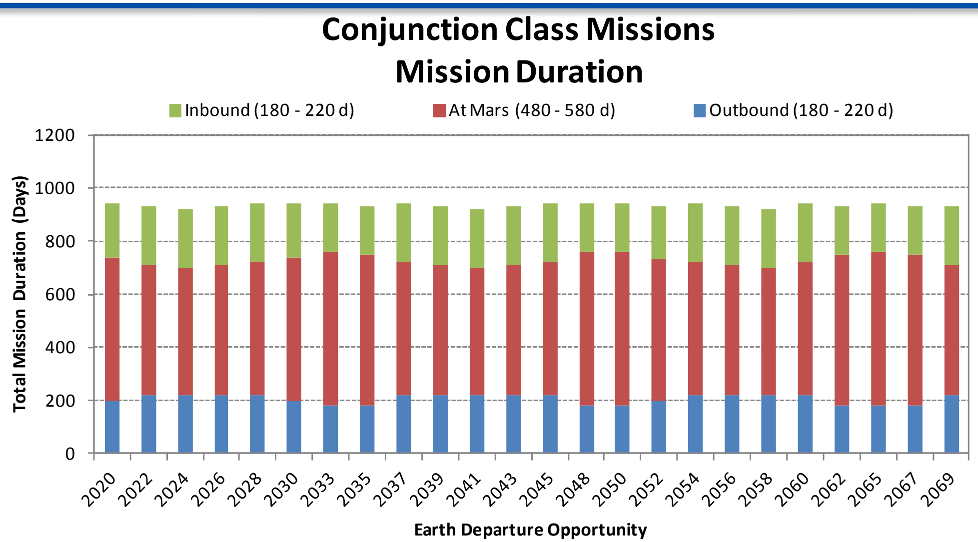
Notes:
- Approximate results only.
- Further assessments required.
- Results are cumulative and thus dependent on combinations/sequences of technologies applied
- The change between points shows the relative mass savings for that particular technology

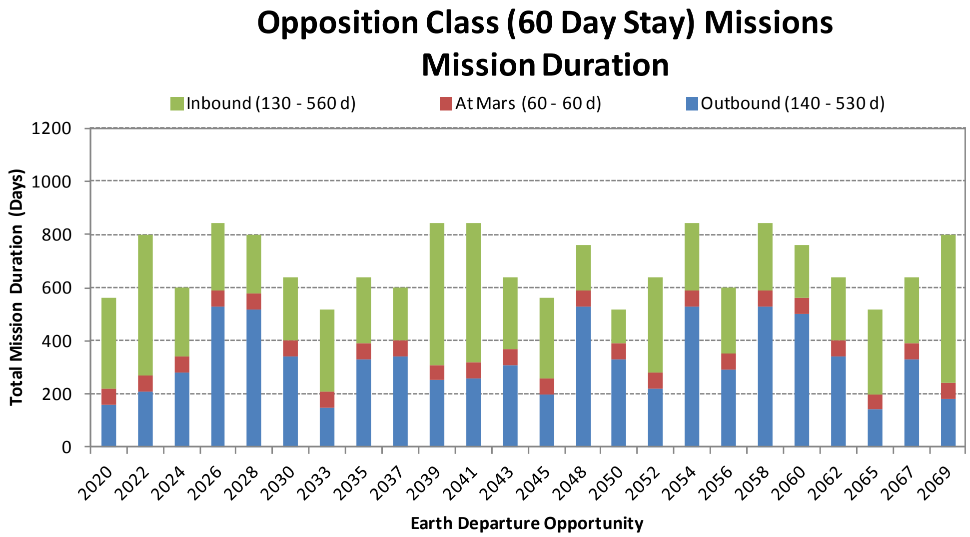


BACKUP

Additional slides

Example Variation in Mission Duration





Assumptions

- **Functional assets that will be available for any of these surface scenarios:**
  - Habitation to support a crew of six for an entire 500 sol surface mission (mass is TBD).
  - Personal EVA equipment (pressure garment and PLSS) for all crew members.
  - Surface transportation for crew. Type (unpressurized, pressurized, both) depends on scenario. Mass is TBD.
  - Robotic rovers. Nominally two but possibly more depending on scenario. Mass and range capability are TBD. At least one rover will be maintained as "sterile" for potential use in "special regions" as defined by planetary protection protocols.
  - Drill. Nominally one of these will be carried. Mass and depth capability depends on scenario.
  - Surface science experiments and equipment. Total mass (nominally) 1000 kg. Includes laboratory-type equipment used inside habitat science lab (clean room?), tools and sensors used during EVA activities, and deployed scientific instrumentation. Covers human health experiments (not medical equipment, even if this is dual use), astrobiological experiments, atmospheric experiments, and geological/geophysical experiments. As mentioned above, specific science experiments and equipment would be selected based on the exploration objectives for the site being visited and thus will likely be different for each mission
  - Returned samples. Total mass (nominally) 100 kg, excluding sample container(s). Covers samples from human health experiments, astrobiological experiments, atmospheric experiments, and geological/geophysical experiments.
- **Total mass for all of these functional elements is (nominally) ≤40 MT. The allocation of this total mass to each elements, except as noted above, will depend on the scenario.**
- **Three candidate surface operations scenarios will be assessed initially (discussed on subsequent pages). A three mission campaign will be assumed. The surface location for each mission may not be the same, but returning to a previously visited site is not precluded.**

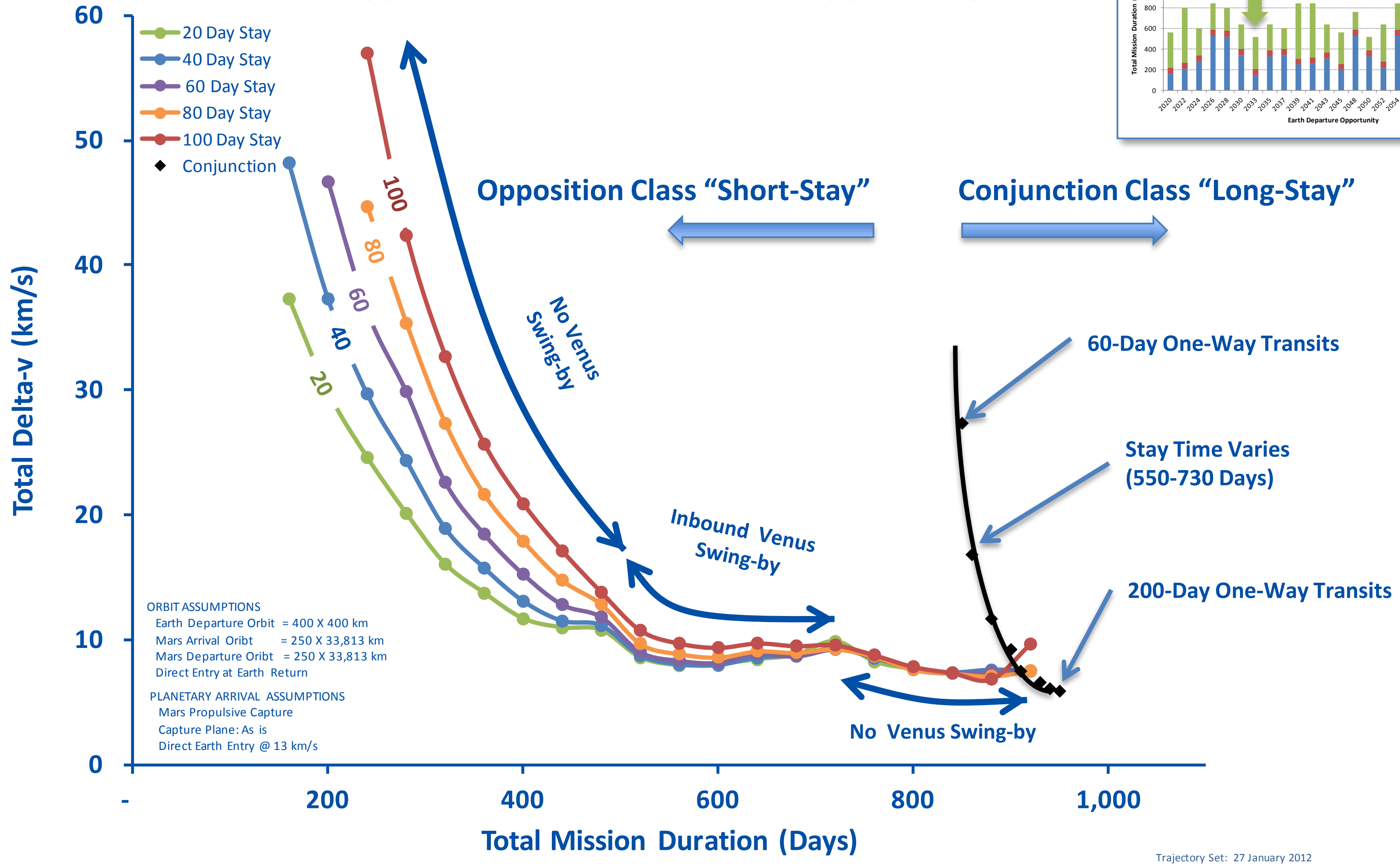
Mars Design Reference Architecture 5.0 Surface Strategy Options

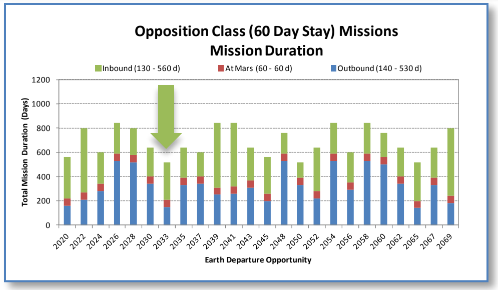
- **Multiple strategies developed stressing differing mixes of duration in the field, exploration range, and depth of sampling**
  - Mobile Home: Emphasis on large pressurized rovers to maximize mobility range
  - Commuter: Balance of habitation and small pressurized rover for mobility and science (DRA 5.0 Reference)
  - Telecommuter: Emphasis on robotic exploration enabled by teleoperation from a local habitat
- **Mobility including exploration at great distances from landing site, as well as sub-surface access, are key to Science Community**
- **In-Situ Consumable Production of life support and EVA consumables coupled with nuclear surface power provides greatest exploration leverage**
- **Development of systems which have high reliability with minimal human interaction is key to mission success**

Surface Mission ConOps Option 2: “Commuter”

- This scenario will have a centrally located, monolithic habitat and two small pressurized rovers. Traverses will not be as long as the “mobile home” scenario (notionally 100 kilometers total distance) and no more than one week duration. Thus on-board habitation capabilities will be minimal in these rovers. However these rovers are assumed to be nimble enough to place the crew in close proximity to features of interest (i.e., close enough to view form inside the rover or within easy EVA walking distance of the rover). Not all crew will deploy on a traverse, so there will always be some portion of the crew in residence at the habitat. The pressurized rovers will carry (or tow) equipment that will have the capability to drill to moderate depths – 100’s of meters – at the terminal end of several traverses.
- The primary habitat will have space and resources allocated for on-board science experiments. The pressurized rovers will carry only minimal scientific equipment deemed essential for field work (in addition to the previously mentioned drill); samples will be returned to the primary habitat and its on-board laboratory for any extensive analysis.
- Long traverses will be accomplished by the pressurized rovers (or possibly robotic rovers) prepositioning supplies in caches along the proposed route of travel prior to the “full duration” traverse. Thus a typical traverse will begin with the crew (or robotic rovers) traveling out a nominal distance (approximately 15 kilometers, or EVA walk-back distance) and establishing a cache of commodities for life support and power (possibly emergency habitation) before returning to the habitat. Some amount of exploration-related activities may be accomplished but the primary purpose is route reconnaissance and cache establishment. The crew then makes another traverse, establishing a second cache a like distance beyond the first cache. This process continues until all caches in this chain are built up sufficiently for the crew, in the two pressurized rovers, to make the entire round trip traverse for the time duration needed to accomplish traverse objectives. The amount of time required to set up and retrieve these supply caches will depend on the specific conditions for a traverse. However, the timeline on the facing page illustrates how much can be accomplished if approximately two weeks are allocated for establishing this string of caches and another two weeks to retrieve them. In addition, not all traverses will be long enough to require this type of support. A mixture of cache-supported and unsupported traverses has been illustrated. Finally, some amount of time will be required to repair and restock the pressurized rovers after each traverse, as well as conduct any local experiments and plan for the next traverse. A notional two weeks between short traverses and four weeks between long traverses has been illustrated.
- As in Option 1, there will be an ISRU plant at the landing site/habitat site making the same kinds of commodities. The habitat will serve as the pantry and maintenance/repair facility described in Option 1.

Example Delta-v versus Mission Duration





Example Delta-v versus Mission Duration