National Aeronautics and Space Administration

Instruments Needed for a Human Exploration Mission of Phobos and Deimos

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Mars-Phobos-Deimos Destination Mission Concept Study Overview

- **Human Spaceflight Architecture Team (HAT) Cycle 2012-A cross-Agency effort to develop a preliminary Destination Mission Concept (DMC) for the Martian moons and provide inputs for establishing a Design Reference Mission (DRM)**
- **Initial effort to identify the science and exploration objectives and explore the capabilities and operations concepts required for a human orbital mission to the Mars system and identify robotic precursor requirements**
- **The Mars-Phobos-Deimos (MPD) mission includes visiting one or both of the Mars moons and permits the teleoperation of robotic systems by the crew**
- **The MPD DMC is 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**
- **Identify potential synergistic opportunities via exploration of cis-lunar space and NEAs**

Phobos and Deimos

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 (days)	**1.26 (Synchronous)**

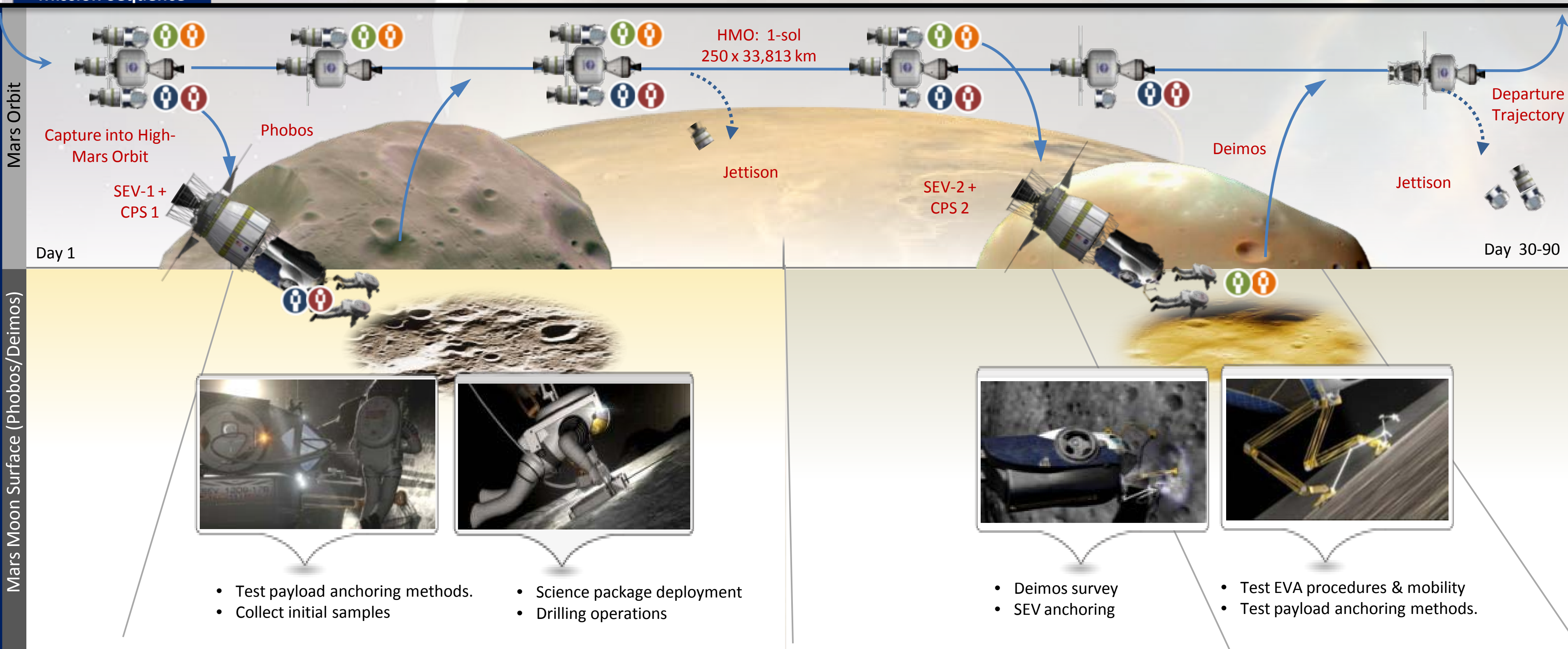
Color-enhanced view of Deimos was taken on Feb. 21, 2009 by the High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter. Deimos has a smooth surface due to a blanket of fragmental rock or regolith, except for the most recent impact craters.

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 (days)	**0.32 (Synchronous)**

The High Resolution Imaging Science Experiment (HiRISE) camera on NASA's Mars Reconnaissance Orbiter took this image of Phobos on March 23, 2008. Taken from distance of ~6,800 kilometers. Combined data from camera's blue-green, red, and near-infrared channels.

Notional Concept for Short-Stay Mars Vicinity Operations

Mission Sequence



Mission Summary

Assumed Mars Orbit Strategy

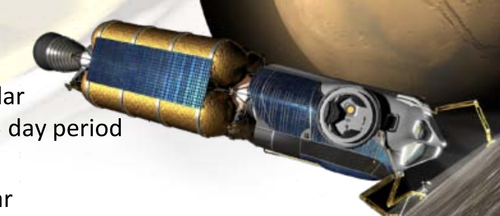
1. Capture into a 1-sol parking orbit with proper plane change to match departure asymptote
2. Leave Mars Transfer Vehicle in 1-sol parking orbit
3. Prepare for orbital operations
4. Utilize SEV-1 to explore Phobos for TBD days (~1,370-3,170 m/s ΔV required)
5. Utilize SEV-2 to explore Deimos for TBD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

Mission Site: Phobos / Deimos

Crew: 4

Deimos:
23,459 km ~circular
0.9 deg incl., 1.26 day period

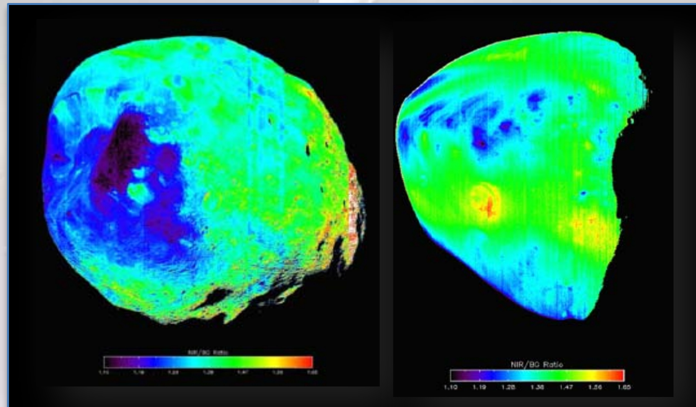
Phobos:
9,378 km ~circular
1.1 deg incl., 0.32 day period



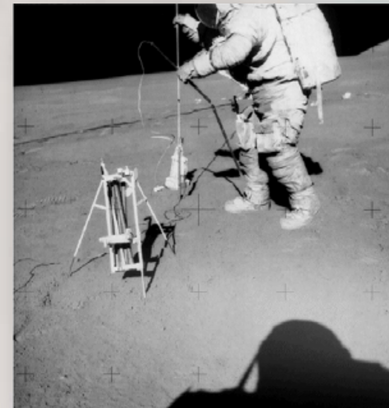
Science at Phobos and Deimos

- **Study of Phobos and Deimos correlates to MEPAG objectives, all science themes in the Small Bodies Assessment Group (SBAG) Roadmap, and includes opportunities for other science activities during transit to/from the Mars system (e.g, astrophysics, heliophysics, life science, etc.)**
- **Highest-priority science is based on sample return and deployment of assets, taking advantage of human crew**
  - Small body origin/geology: Field science, sampling, geophysical station deployment
  - Mars geology: Search for Martian meteorites on Phobos
  - Collect Mars Sample Return (MSR) sample cache
- **Recommendation to visit both Phobos and Deimos, with higher priority for Phobos, based on the current state of knowledge**
- **Recommendation that a precursor mission includes science observations necessary to inform human exploration planning (e.g., relative science significance of Deimos vs. Phobos)**
- **Applications of teleoperations to Mars surface are unclear and require further study**

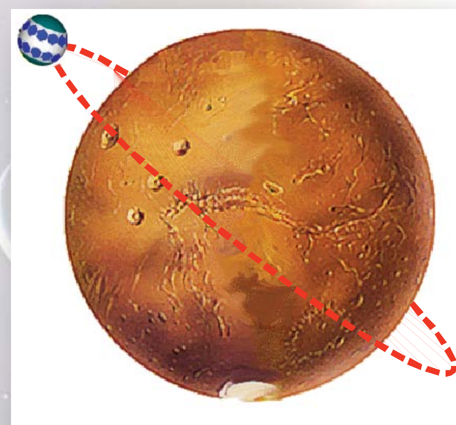
Science Objectives



Determine the nature of the surface geology and mineralogy



Characterize the regolith and interpret the processes that have formed and modified it

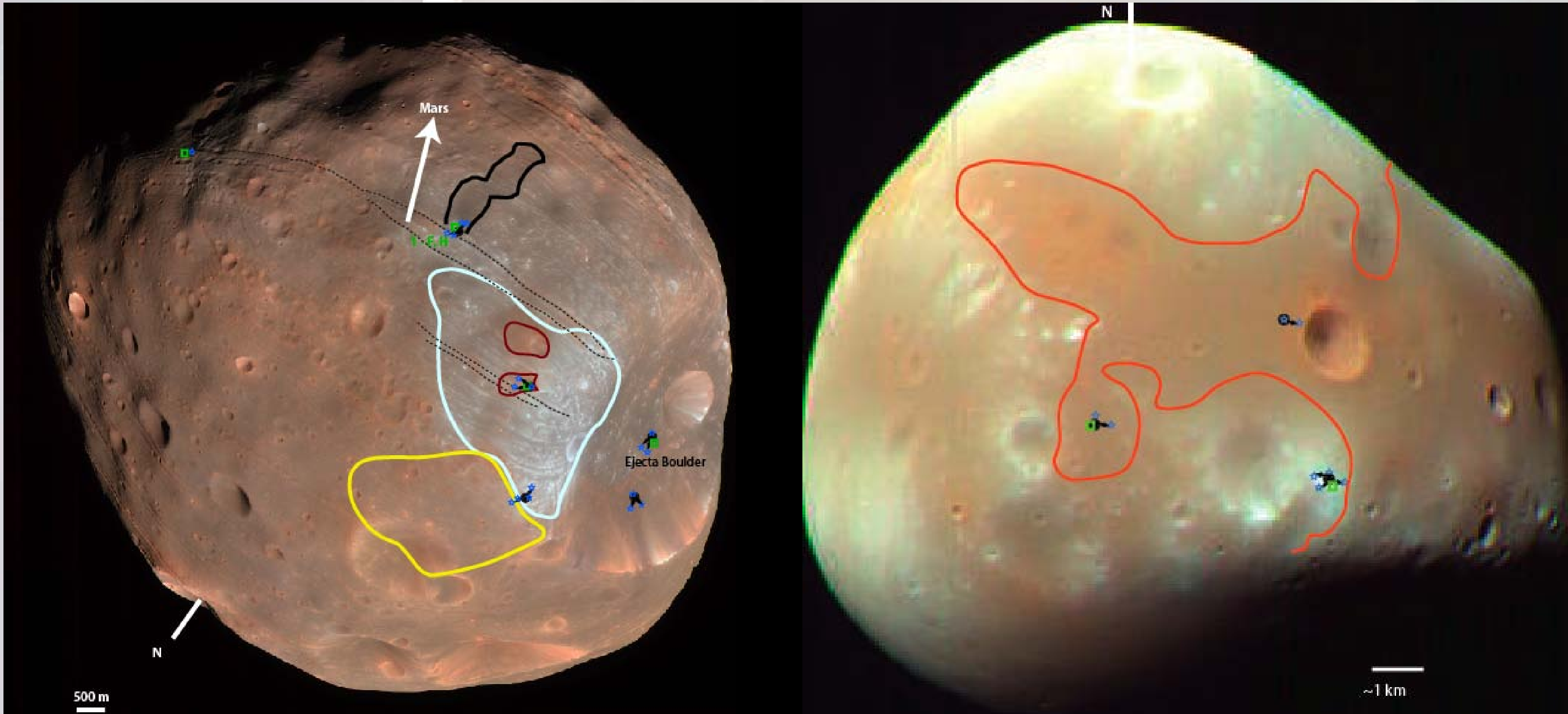


Complete the MSR Campaign: capture and return the orbiting cache of samples to Earth

Collect Mars meteorites from the surface and return to Earth for detailed study

Determine the absolute material ages and constrain the conditions of formation

Reference Landing Sites



Legend			
Petrological (spectral) Unit		Landing site	
Tectonic Feature		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 (e.g. precursor mission)

Science Priorities and Implications

SCIENCE PRIORITY	IMPLEMENTATION IMPLICATION
Field science at surface	a) Use of extravehicular activity b) Need for surface mobility c) Maximize contact time between astronauts and geology d) Multiple sites to sample surface diversity
Regolith science	a) Method of acquiring samples from depth (~2-3 m) b) Multiple sites to sample surface diversity
Returned sample science	a) Field instruments to support sample selection, sample acquisition tools, sample packaging/ containers b) Samples from multiple sites needed to capture material diversity c) A plan for returned sample mass
Long-term monitoring	a) Monitoring instruments set up by the astronauts and left behind on the surface
MSR Sample Cache	a) Autonomous or performed by the crew requires further analysis
Telerobotics to Mars surface	a) Priority is unclear -- science drivers are not well defined b) Time and position of the astronauts unclear c) Necessity for pre-deployment of assets unclear

Transit Science

- **Prospective transit science opportunities are manifold**
  - Venus flyby: likely included during an opposition-class mission
  - Other Planetary Science: micrometeroid monitoring, dust collection, etc.
  - Heliophysics: Sun's polar magnetic field and solar wind characterization, deployment and retrieval of GAS can/SPARTAN-like payloads
  - Astrophysics: observation of Earth as an exoplanet, planetary microlensing events
  - Biomedical: monitoring the impact of radiations, microgravity, of solar protons and galactic cosmic rays on cellular material, of the human immune system, of muscular and cardiovascular performance
  - Psychological: monitoring the impact of confinement, stress hormone levels, sleep patterns, response to altered lighting
- **Humans can significantly increase the science returned during transit**
  - Crew can make real time adjustments during encounter to maximize science without time delay and sequencing issues
  - Crew can deploy/retrieve equipment repeatedly and return for examination on Earth
- **Transit science events will be in rhythm with the mission and provide opportunities for public engagement**

Human Exploration Objectives and Implications

EXPLORATION OBJECTIVES	IMPLEMENTATION IMPLICATION
Obtain knowledge of Mars, its moons, and the surrounding environment	a) Data to develop gravitational potential models b) Imagery of TBD resolution with altimetry of the entire surfaces c) SPE and GCR radiation measurements from orbit d) Data to develop preliminary geological maps e) Civil engineering data for safe landing and operations
Conduct technology, operations, and infrastructure demonstrations	a) Exercise Mars surface sample return protocol b) Collect system performance data (life support systems, power, etc.) c) Exercise independent crew operation procedures d) Exercise orbital operations (e.g., rendezvous with a suitable target e) Demonstrate in-situ resource utilization (ISRU)
Incorporate partnerships that broadens overall organizational participation	a) International Partner contribution of mission elements, experiments, and other equipment b) Use of commercially available elements with (potential augmentation) to meet mission requirements c) Include partnerships as applicable with other US government agencies
Incorporate multiple public engagement events	a) Perform an early mission to the Martian system to engage the public and maintain interest in Mars surface mission b) Include student experiments and projects (allocate time, mass, power, etc.) c) Include time in scheduled crew activities for public outreach activities during all mission phases
Prepare for sustained human presence	a) Catalog elements and minerals types and concentrations on the surface and subsurface b) Surface and near subsurface “civil engineering” properties c) Long duration Mars atmospheric observations; d) Demonstrate ISRU processes for applicable mineral types d) Demonstrate key elements (TBD) of long term orbital infrastructure

Instrument and Tool Categories

- Astronaut-held instruments used while investigating the surface
- Autonomous, mobile instrumented platforms to increase the spatial extent of exploration at landing sites
- Instruments deployed on Phobos-Deimos by the astronauts and left behind for long-term monitoring
- Spacecraft-mounted and astronaut-tended instruments used during cruise and for reconnaissance at the targets
- Spacecraft-mounted instruments controlled by a science team on Earth. For example, spectrometers or cameras where there is no need for local human assistance.
- Tools and packaging for sample collection
- Terrestrial laboratories for returned sample science

Technology Areas to be Developed Prior to Human Exploration of Mars, Phobos, and Deimos

- **Handheld instruments/tools**
  - low mass
  - compact
  - reliable/durable
  - low integration/preparation time for rapid data acquisition
  - rapid recharge capabilities
- **Autonomous mobile assets**
  - controllable
  - reliable guidance, navigation, and control, and refined autonomous functions for close crew support under micro- or low-gravity conditions
  - miniaturization of sensors and instruments
- **Deployable instruments**
  - compact enough for crew deployment
  - power systems for long duration (rechargeable, high-efficiency, e.g., solar and fuel cells, batteries, etc.)
  - adapted to long-term survival in aggressive/hazardous environment (e.g., low gravity conditions, particulates, thermal, plasma, electrostatic, etc.)
- **Tools/Instruments for sample collection and storage**
  - miniaturization and adapted for micro- or low gravity conditions
  - the collecting tools may be the preferred method for containment and stowage of the sample (e.g., core tubes)

Further Thought

- The analysis of the Phobos/Deimos Design Mission Concept has highlighted the need for future development of potential instruments and tools to be utilized by a human crew
- Current technology readiness levels for instruments/tools should be improved in order to further serve NASA's human and science exploration goals
- NASA's exploration and scientific communities should work together with academic and private institutions to identify mission instruments, techniques, and tools that would be used for future human missions to destinations beyond low-Earth orbit