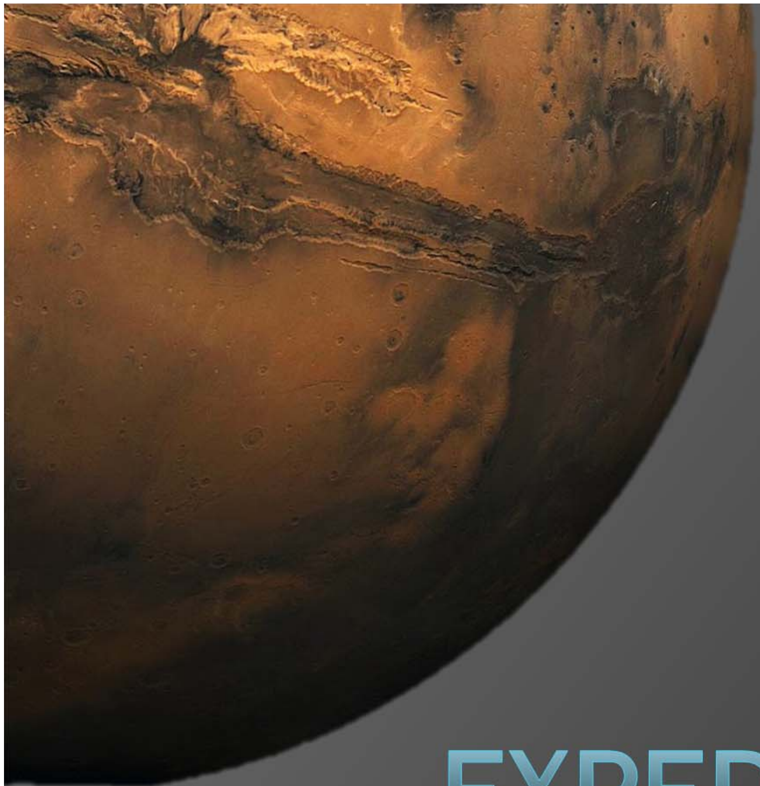
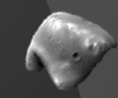
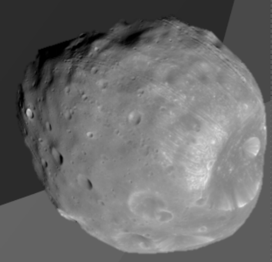


EXPEDITION ASAPH

TEAM VOYAGER





Mission Statement

To design a mission to land humans on a Martian moon, either Phobos or Deimos, and return them safely to the Earth along with a sample; with a launch date no later than January 1, 2041.

Motivation

- Advancing Human Exploration
- Science
- Planetary
  - Composition, age, and origin
    - Is there water?
  - Relation to Martian system
- Biological

Motivation: Phobos vs Deimos

Deimos

Phobos

- Geological considerations
  - Composition
    - Organics
    - Water

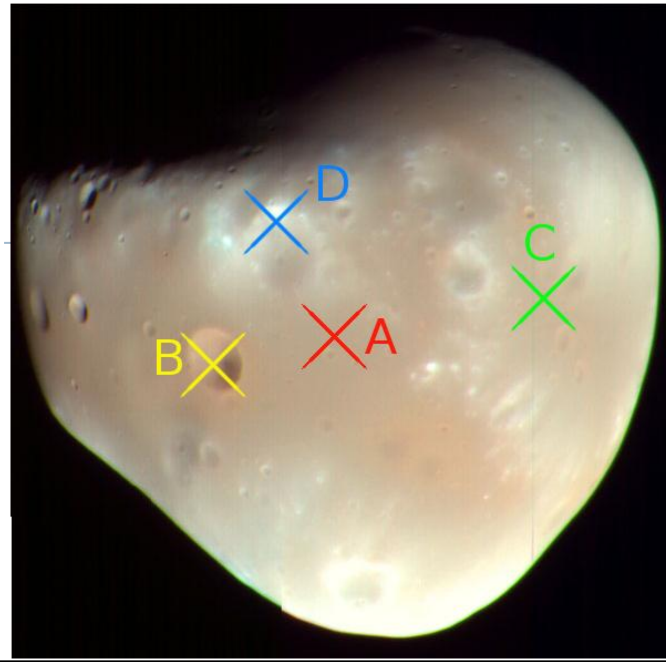
Mission Overview

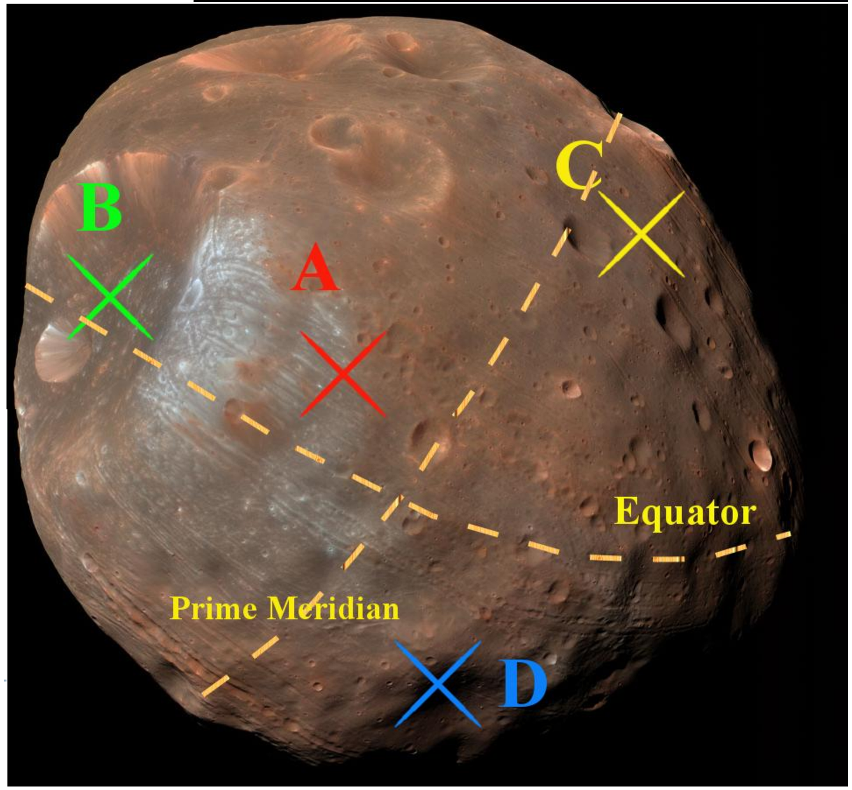
The Asaph mission is divided into two phases

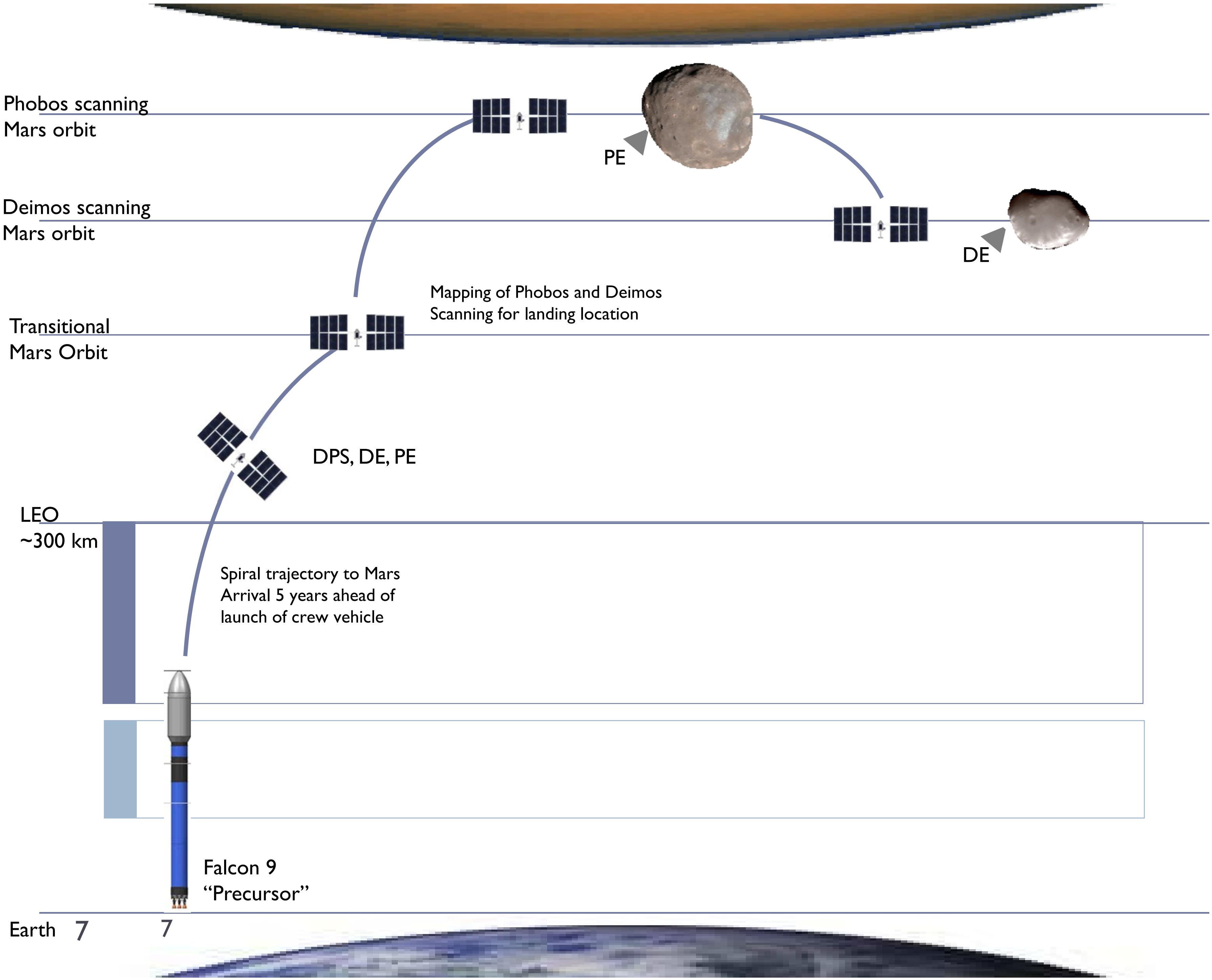
- The precursor phase, aimed to provide data on the topography and composition of Phobos and Deimos to assist in planning and technology development
- The primary phase, in which the crew will travel to the Martian system to conduct their exploration and sample retrieval tasks.

Precursor Mission: Goals

1. Can humans land safely on Phobos or Deimos (alternate)?
   a. remote observation, in situ, impactor.
2. Set up communication system for the main mission.
3. Accomplish some mission science objectives, if possible.



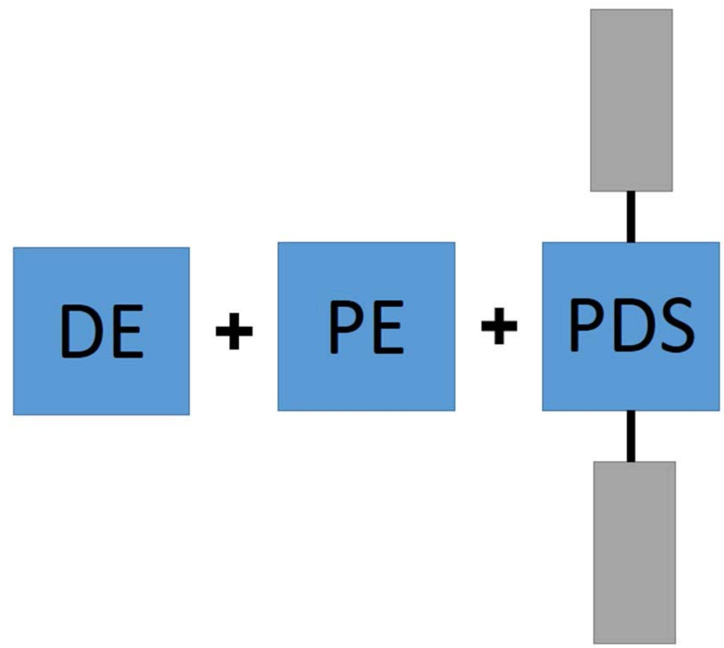




Phobos scanning
Mars orbit
PE
Deimos scanning
Mars orbit
DE
Mapping of Phobos and Deimos
Scanning for landing location
Transitional
Mars Orbit
DPS, DE, PE
LEO
~300 km
Spiral trajectory to Mars
Arrival 5 years ahead of
launch of crew vehicle
Falcon 9
"Precursor"
Earth

Precursor Mission

- Robotic survey mission to Phobos and Deimos
- Launches in a Falcon 9 in 2026
- Uses solar electric propulsion
- Arrives at Mars in 2028
- Components:
  - PDS (Phobos Deimos Surveyor)
  - PE (Deimos Explorer) =
    lander + impactor
  - DE (Phobos Explorer) =
    identical lander + impactor



Instrument Payloads

- Soil properties--strength, chemistry, mineralogy
  - Wet chemistry Lab, LIBS, X-ray diffraction/fluorescence, spectral imaging, elemental/molecular abundance
- Topography, spin rate profile
  - LIDAR
- Water abundance (near-surface/sub-surface)
  - Penetrator, seismometers
- Magnetic field
  - Magnetometer
- Flux of interplanetary material
  - Micrometeoroid detector

Building blocks

Deep Space Habitat

Mass: 45 t
Power: 12kW
Habitable volume: 76.3 m^3
Based on existing ISS modules

Orion MPCV

Mass: 30t
Power: 9kW

Nuclear Thermal Rocket

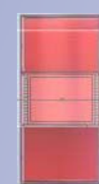
Dry mass: 21t
LH2 mass: 28t
Isp: 900s
Thrust:: 2x111kN
Diameter: 5m

Space Exploration Vehicle

Total mass: 12t
Power: 4.6kW
Includes 3 EVA suits, robotic arm, misc. equip.
CH4/O2 mass:: 4.3t

LH2 Tank

Dry mass: 10t
LH2 mass: 37t
Volume: 522 m^3
Robotic docking capability

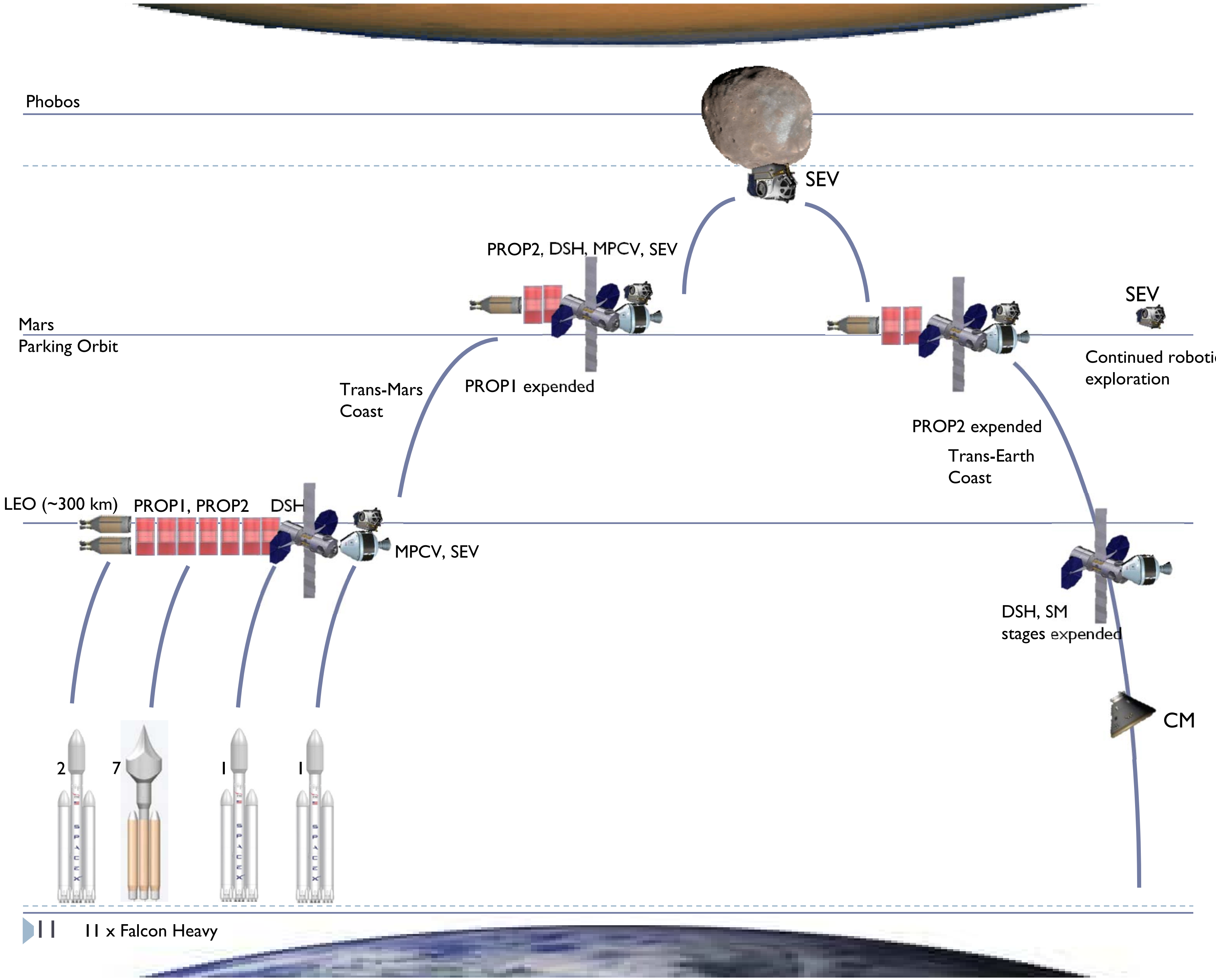


Phobos/Deimos Explorer

Mass: 1t
Includes impactors as well as landing equipment

Phobos-Deimos Surveyor

Mass: 5.4t
Power: 9.3kW
Based on MRO
Includes SEP and fuel



11 x Falcon Heavy

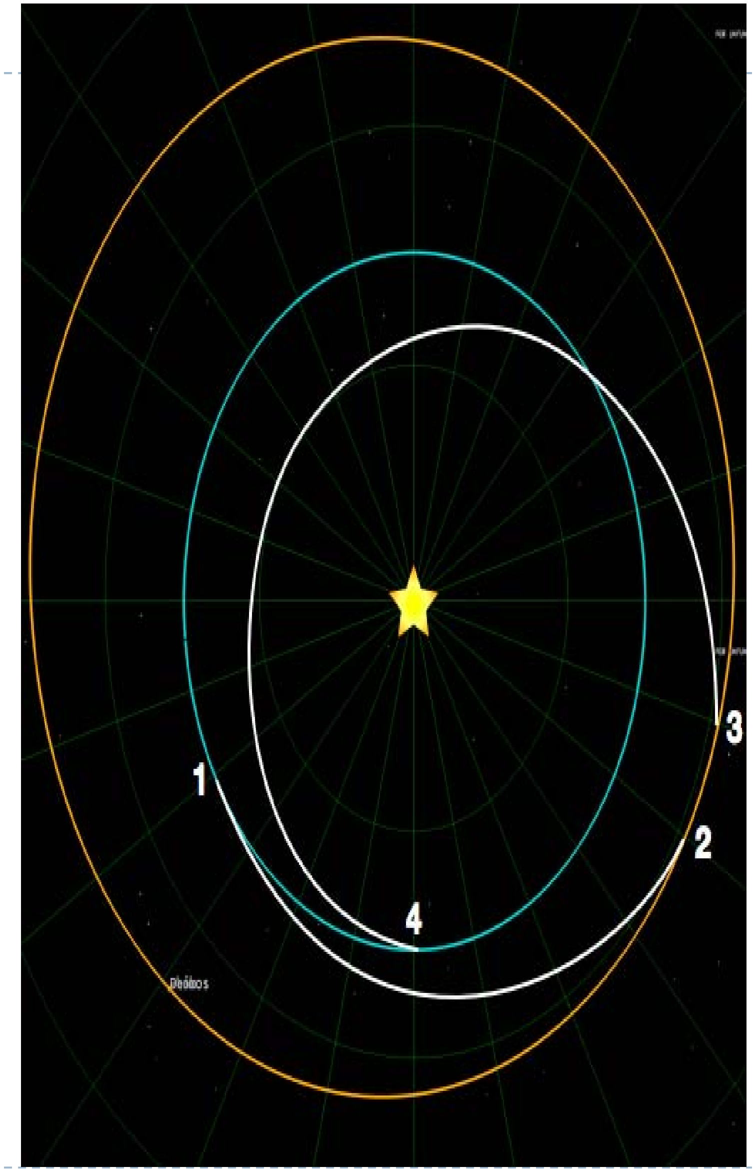
Trajectory

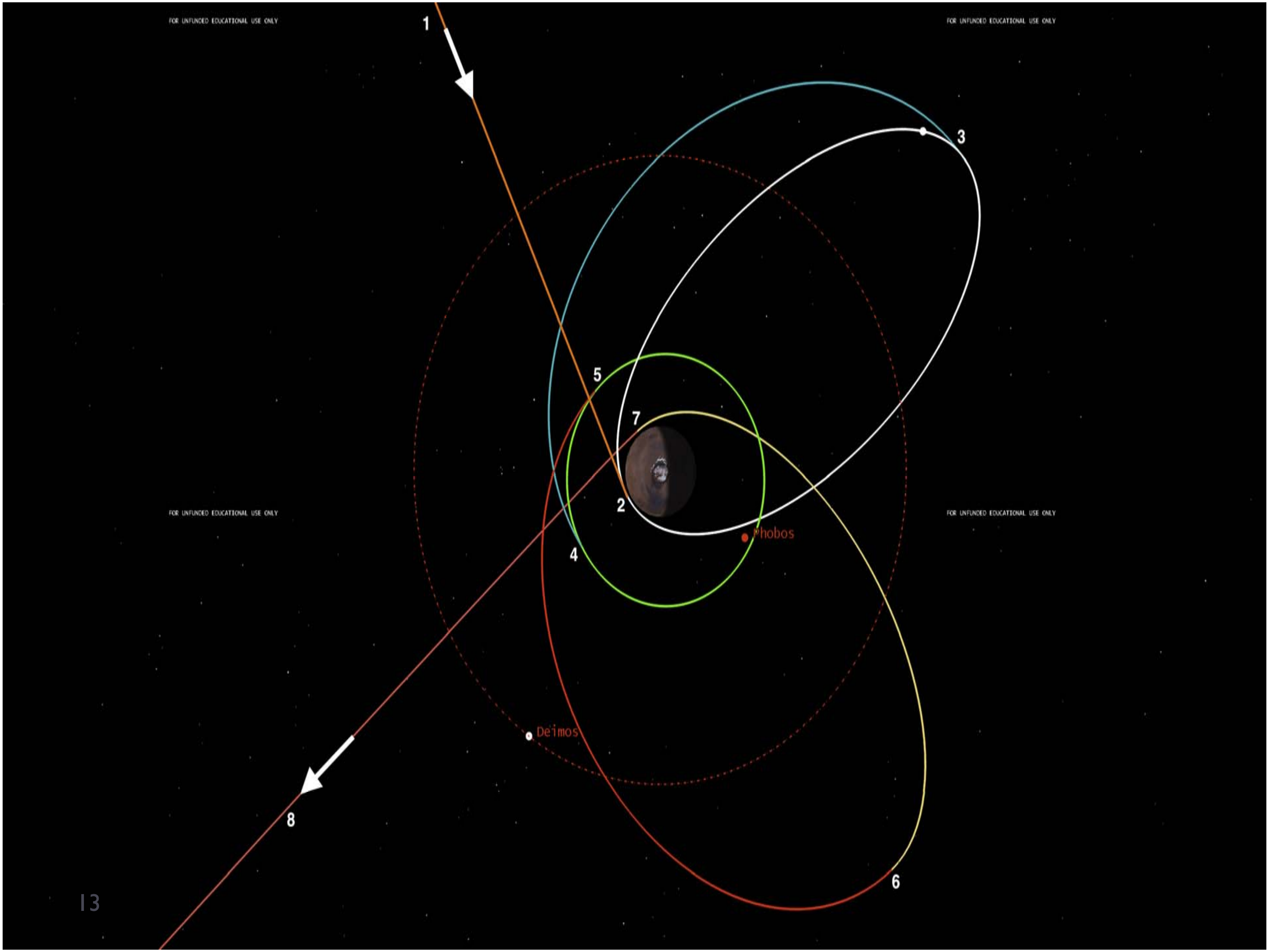
Considerations:

- Radiation exposure
- Bone mass loss
- Solar cycle
- Launch window
- Earth line-of-sight

Accommodations:

- Galactic cosmic rays
- Jazzercise
- Solar maximum
- Minimal weather delays
- Social networking

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Phobos
Deimos

Vehicles and Propulsion (1/2)

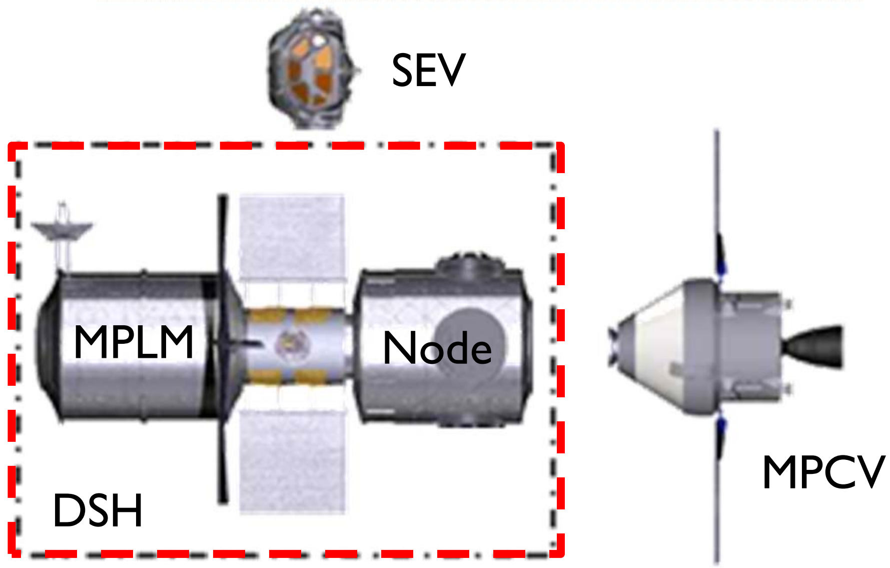
- Propellant mass estimates for the mothership based on Δv
- Trade-off between
  - LEO vs. HEO
  - CPS vs. NTP
  - Operations at Phobos (moving whole mothership vs. only SEV)
- Detailed design of NTP system
  - Estimating engine core mass and structure, scaled for higher thrust requirement
  - Modification of launcher fairing size to an aerodymamic shape to increase payload volume
- Trade-off between four different launcher combinations (Falcon Heavy, Atlas V, SLS, Atlas/Falcon)
- Margin of 10% on every propellant mass

Vehicles and Propulsion (2/2)

- Design choice: Nuclear thermal propulsion with 2 Engines, each 222 kN thrust and 900s I_{sp}, launching from LEO

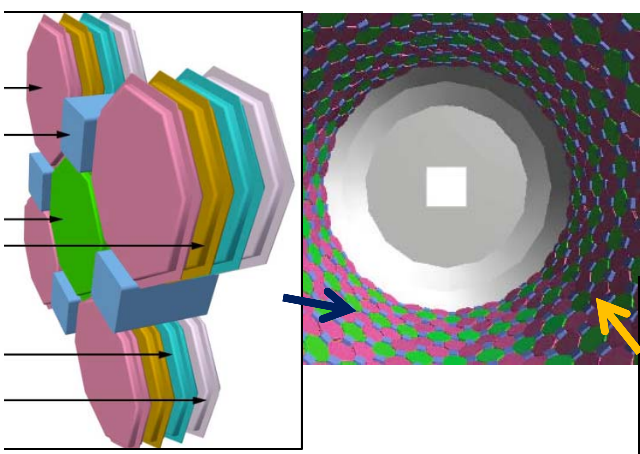
	Falcon Heavy	SLS Crew/Cargo I+II	Atlas V HLV	Atlas/Falcon Heavy
Performance [t]	**53**	70/120	29.4	29.4t/53
Number of launches	**11**	6	17	13
Estimated launch cost [$M]	**880-1,375**	2,580-12,625	1,625-1,880	1,445-1,715

Habitat Design: Deep Space Habitat



- Sized for 460 days
- Closed loop ECLSS
- Atm: 101.3kPa (14.7psi), 21% O2
- Special features
  - ISS derived structure
  - Hybrid ECLSS system (Water Walls & Adv. Tech. derived from ISS research)

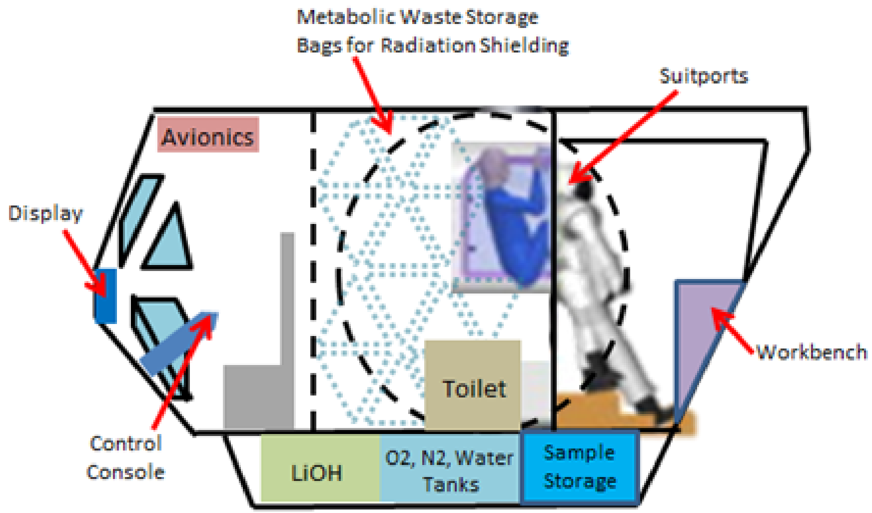
Function	**Technology**
Carbon Dioxide Reduction	Bosch Reactor
Waste Water Management	Vapor Phase Catalytic Ammonia Removal (VCPAR)
Air Monitoring System	ANITA 2
Waste Management	Heat Melt Compactor



Water-Wall Concept

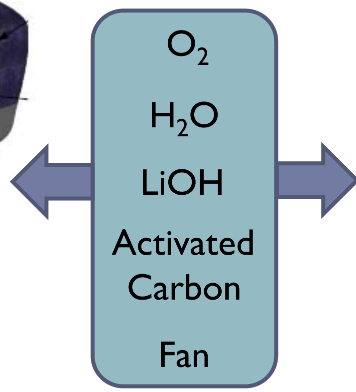
Waste "Puck"

Habitat Design: Space Exploration Vehicle



- Sized for 30 days, 2 crew with 8 (+2) EVAs
- Open Loop ECLSS – Maximize Reliability
- Atm: 70.3 kPa, 26.5% O2
- Special Features
  - Suitports = "No-prebreathe" EVA with selected spacesuit (Mark III)
  - Leveraging commonality
  - Using waste products as radiation shielding

SEV



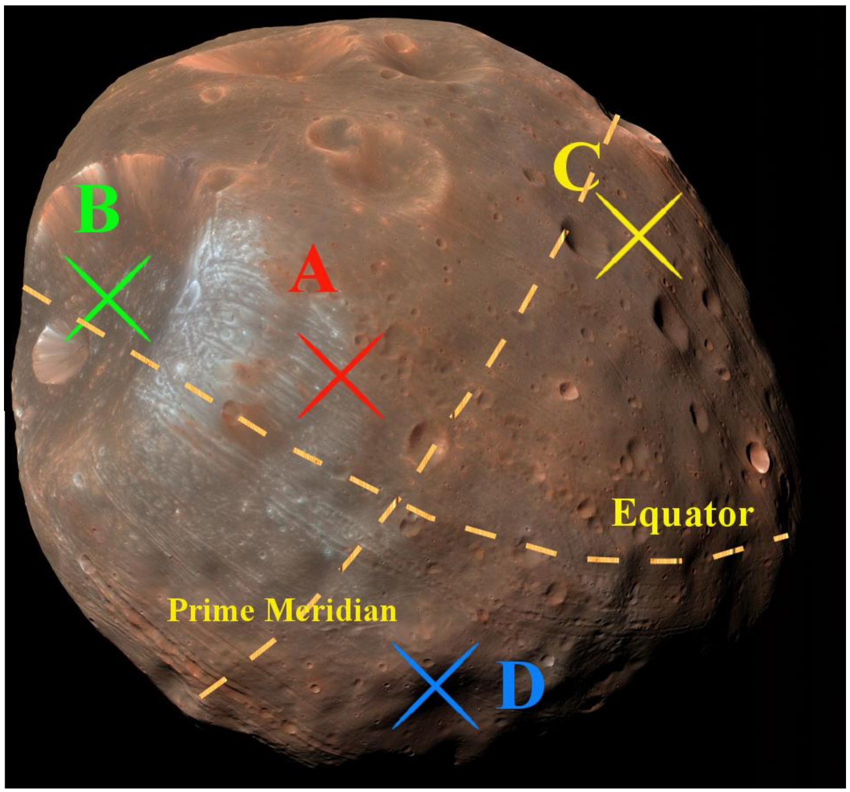
Mark III Suit

Function	**Technology**
Oxygen Supply	Pressurized Oxygen Tanks
Water Supply	Pressurized Water Tanks
Carbon Dioxide Removal	LiOH Canisters
Contaminant Control	Activated Carbon
Ventilation	Common Fan

Human Factors & Crew Health

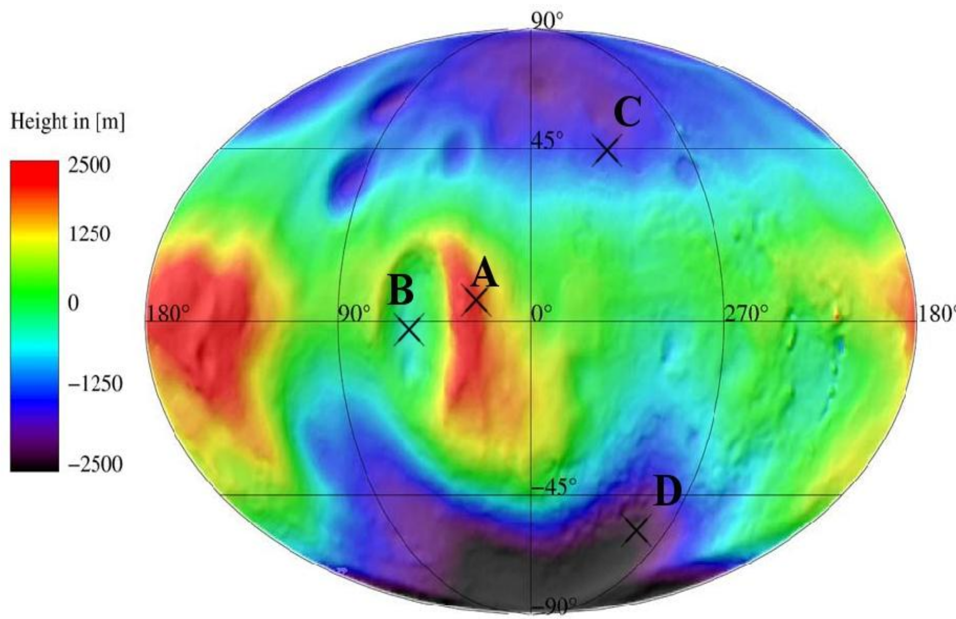
- Keeping crew alive, healthy and happy to complete mission objectives
- Crew size and selection
  - 3 person crew, ages 40-55 preferred
  - Extensive training in geology, vehicle maintenance, and medical event management
- Habitable Volume = 25.5 m^3 per person, individual crew quarters
- Crew Health Care
  - Crew health monitoring
  - Biomedical countermeasures
  - Psychological countermeasures
  - Utilizing CHeCS and ISS Medical Kits as baseline medical supply design

Site Location Selection



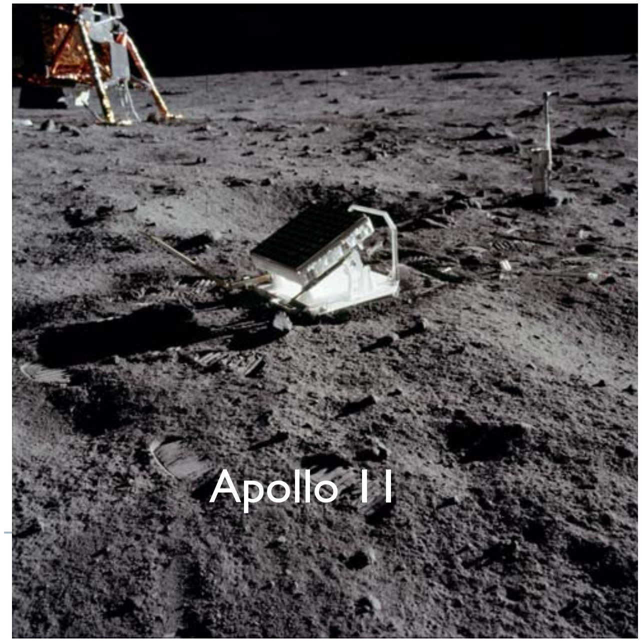
Landing Site Options

Elevation Map of Phobos



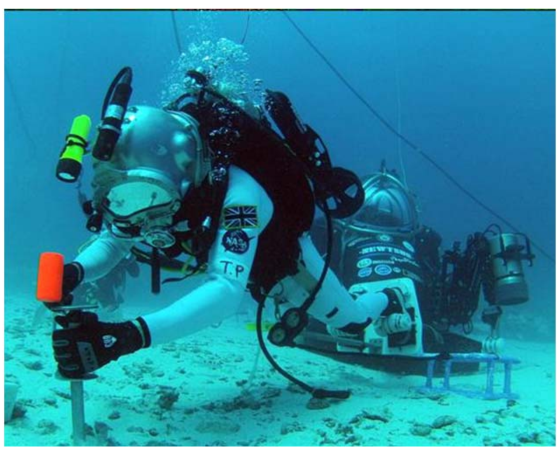
Main Mission science equipment

- sample containers for rocks and soil
- core drilling equipment
- seismometers and possibly seismic source
- retro-reflector for long-term laser ranging
- nanosat release



EVA Mission Operations

- Two operational modes for EVA
  - MODE I – Thick dusty layer terrain
    feet fixed to robotic arm
  - MODE II – Rockier or gravel terrain
    tethered to SEV, held in place with ground anchor
- Sample Collection & Instrument Placement



EVA Mode I

EVA Mode II

Bioscience Payload

- In-flight Bioscience Instrument Suite
  - Molecular Analysis (Hormones, Biomarkers, etc.)
  - Ion Analysis
- Academic and industry linkage
- Sample preservation and return minimized by design
  - Modified-MELFI (freezer) when necessary
- Outcome
  - Mid-mission countermeasure customization
  - Deep space health data

Planetary Protection

- Phobos: "Restricted Return"
- Back Contamination Mitigation
  - Risk to Earth and crew
- Breaking the Chain
  - Primary sample containment sterilization using Vapor Phase Hydrogen Peroxide Airlock on DSH
  - Final containment units in DSH must survive atmospheric entry and surface impact at Earth.

Public Outreach

- University and Coporation Science
  - Competition open prior to launches.
  - Astronauts to release science on Phobos
  - Public science to further global knowledge
- Internet, i.e. Facebook, Twitter.
- Educational Interaction
- NASA TV

International Collaboration

- Facilitate the cooperation of nations in spaceflight
- Mutually beneficial
  - Financial
  - Scientific
- Infrastructure for further exploration
- Multiple launch sites with international crew will impact more people globally.

Impact

- Continued study of Martian system
- Useful/parallel data to assist NEO operations
- Further knowledge of deep space habitation
- Potential for ISRU initial studies
- Technology Development

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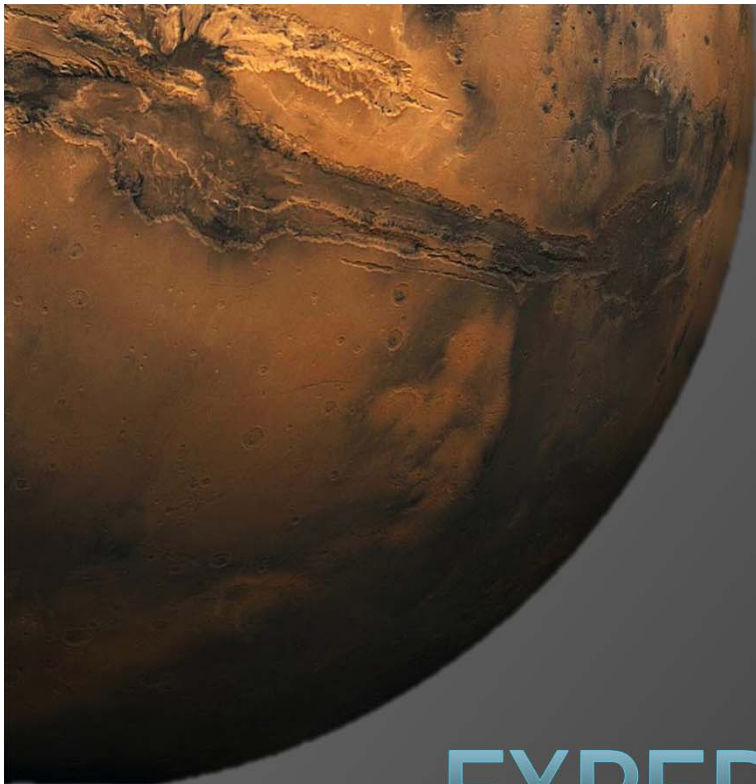
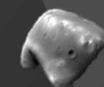
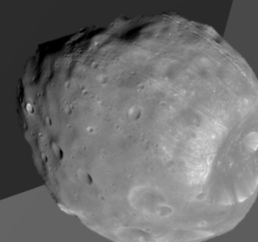




EXPEDITION ASAPH

TEAM VOYAGER



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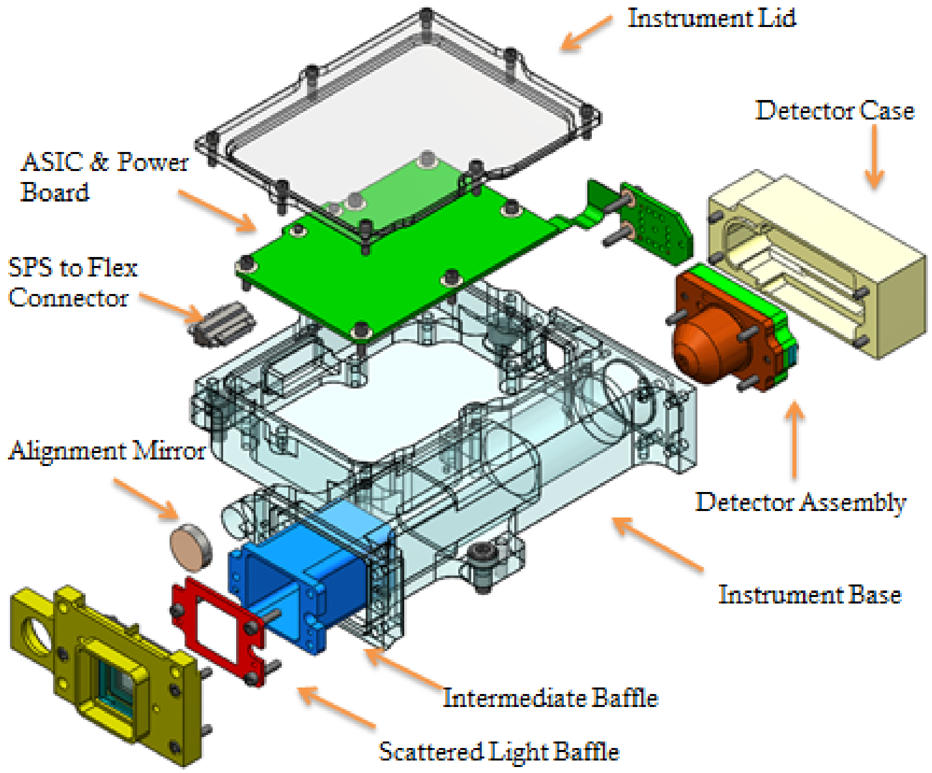
EVA Operations Schedule

Day 1	Secure and EVA prep	
Day 2	EVA, site 1, astronaut 1	Collect contingency sample Surface samples, retro-reflector placement
Day 3	EVA, site 1, astronaut 2	Surface samples, passive seismometer placement
Day 4	Rest day	
Day 5	EVA, site 1, astronaut 1	Core samples
Day 6	EVA, site 1, astronaut 2	Core samples, place public outreach experiments
Day 7	move to site 2, EVA prep	
Day 8	move to site 2, EVA prep	
Day 9	EVA, site 2, astronaut 1	Contingency sample, surface samples
Day 10	EVA, site 2, astronaut 2	Surface samples, passive seismometer placement
Day 11	Rest day	
Day 12	EVA, site 2, astronaut 1	Core samples
Day 13	EVA, site 2, astronaut 2	Core samples, place public outreach experiments
Day 14	Contingency – rest day, post mission activities	

Attitude Determination & Control System

- Essentially all control systems require two types of hardware components: sensors and actuators. Sensors are used to sense or measure the state of the system, and actuators are used to adjust the state of the system. Similarly, the attitude determination and control system for the proposed design typically uses a variety of sensors and actuators. For a better modularisation, ADCS has further been divided into Attitude Determination and Attitude Control.
- Attitude Determination
- In the proposed mission, the attitudinal state of all physical stages are described by three angular variables along x, y and z axes. The coordinate frame is always Body-Centered-Body-Fixed (BCBF). A brief trade study was performed to select appropriate Attitude sensors. The trade was conducted with the single point requirement of reliability and redundancy. Below is the summarized result of the same:
- At the end of the study it was decided that all stages of mission on both precursor and main mission be equipped with a combination of a Star Tracker and a Sun Position Sensor. Rationale behind the selection was:
    1. Non-dependence on moving parts
    2. Extremely light on mass and volume budget
    3. Starfield view availability for a large fraction of orbits
    4. Availability of line-of-sight with Sun during rare Solar saturation
- The system will primarily depend on star tracker for the attitude determination. As a preliminary choice, it is proposed that a system similar to sensing system onboard Clementine Star Tracker Cameras [NSSDC ID: 1994-004A-07] be used. The sensor on board has an extremely low mass of about 300 grams. The star tracker will have full sky map due to the nature of the mission, involving multiple orbital configuration. During times of sun saturation, the system will fall back on sun position sensor which can derive heritage from GOES-15 [NSSDC ID: 2010-008A].

Attitude Determination & Control System



It is believed with a high level of confidence that the above stated two-line system will be reliable. However, as a last line of defense, in case of complete temporary failure, attitude determination can still be performed to within reasonable accuracy using 'see and follow' philosophy depending on sight-sextant.

Attitude Control

- The difference between the desired and measured attitude states is fed into an Attitude Control System which in turn physically corrects the attitude. Several strategies can be employed to achieve this. Some of the options considered for the proposed mission are as follows:
- At the end of the study it was decided that SEV and DSH be equipped with a combination of a Control Moment Gyroscope (CMG) and Monopropellant Hydrazine Thrusters and all stages of phase I and smaller stages of phase II be equipped with just Monopropellant Hydrazine Thrusters. Rationale behind the selection was:
    1. Non-dependence on magnetic field, gravity gradient,
    2. Tried and tested nature of technologies involved
    3. Sufficiently capability for relatively fast maneuvers
    4. Sufficiently high level of achievable precision
- Since SEV and DSH are the only very massive stages, they require special attention. It is being proposed that 3 single-gimbal CMG's be used on SEV and DSH. In addition there should also be a backup system of monoprop thrusters using Hydrazine. This will provide a three-axis control with built-in contingency fall back while maintaining simplicity and reliability. It is believed with a high level of confidence that the above stated two-line system will be reliable. However, as an absolute last line of defense, in case of complete failure, SEV's attitude can be somewhat controlled by robotic arm in the proximity of the Phobian surface.

The following is a broad quantitative justification for the above decision using first order approximations:

SEV

Mass: 14 metric tonne

Torque capacity of modern day CMG with a 100 kg is about ~ 2000 N.m

Along perpendicular Axis (y -axis and z-axis)

Moment of Inertia along principal axis: 38,573 $kg \cdot m^2$

Start Slew Rate: ~ 2.5 °/sec

Along Transverse Axis

Moment of Inertia along principal axis: 53,235 $kg \cdot m^2$

Start Slew Rate: ~ 6 °/sec

DSH

Mass: 47 metric tonne

Torque capacity of modern day CMG with a 100 kg is about ~ 2000 N.m

Along perpendicular Axis (y -axis and z-axis)

Moment of Inertia along principal axis: 661,917 $kg \cdot m^2$

Start Slew Rate : ~ 0.1 °/sec

Along Transverse Axis

Moment of Inertia along principal axis: 237,938 $kg \cdot m^2$

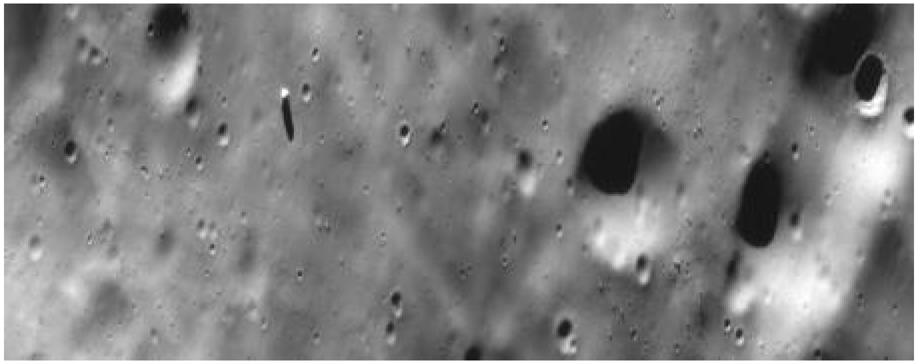
Start Slew Rate: ~ 0.24 °/sec

Communications

- Voice, video, telemetry links required
- Telemetry link is used to transmit text messages to crew. Voice and video are used only occasionally.
- Direct to Earth (DTE) communication using Ka-band on Deep Space Network. Communication to Earth via DPS orbiter and communication between crew vehicles over UHF band.

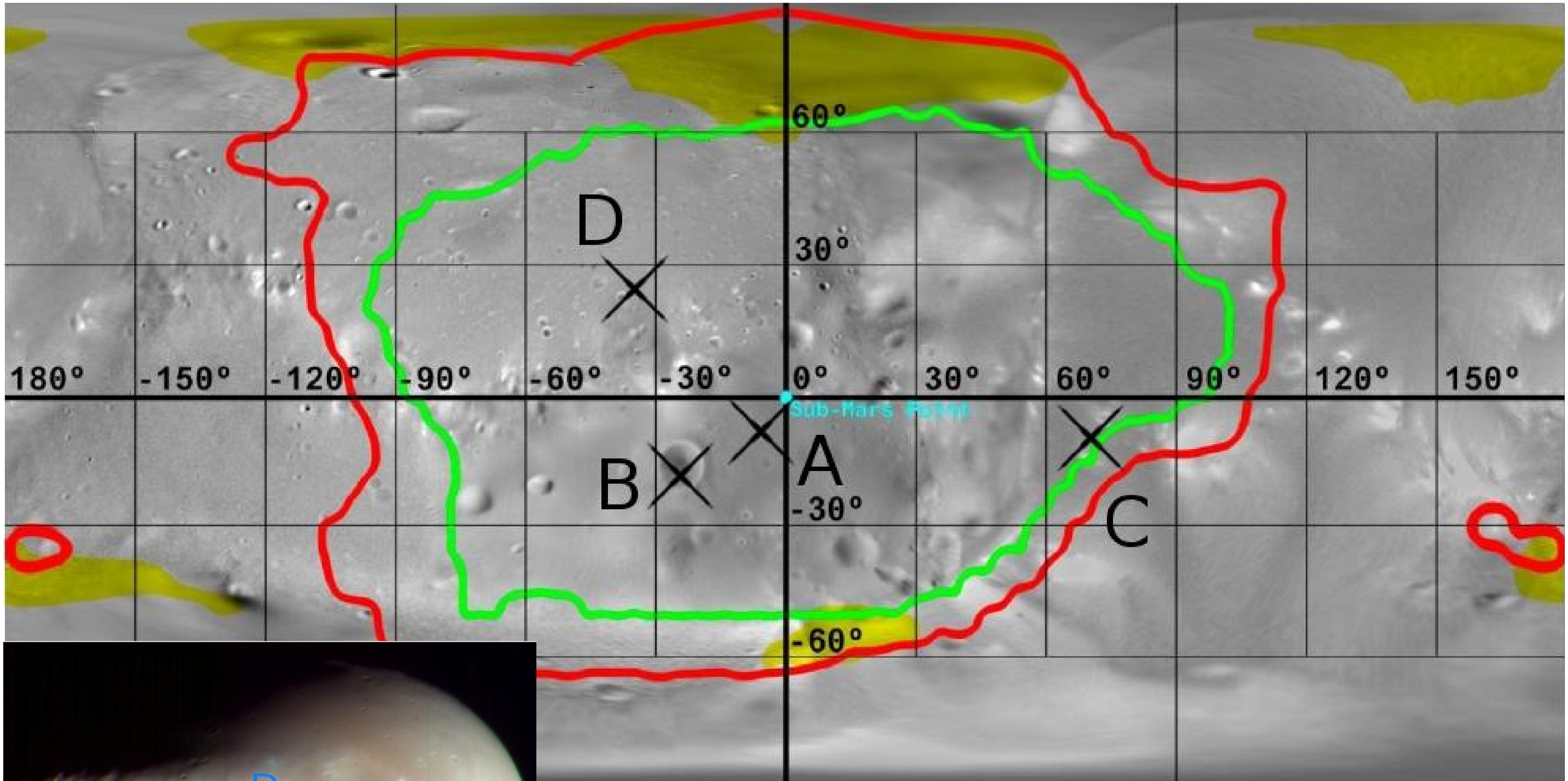
Communications

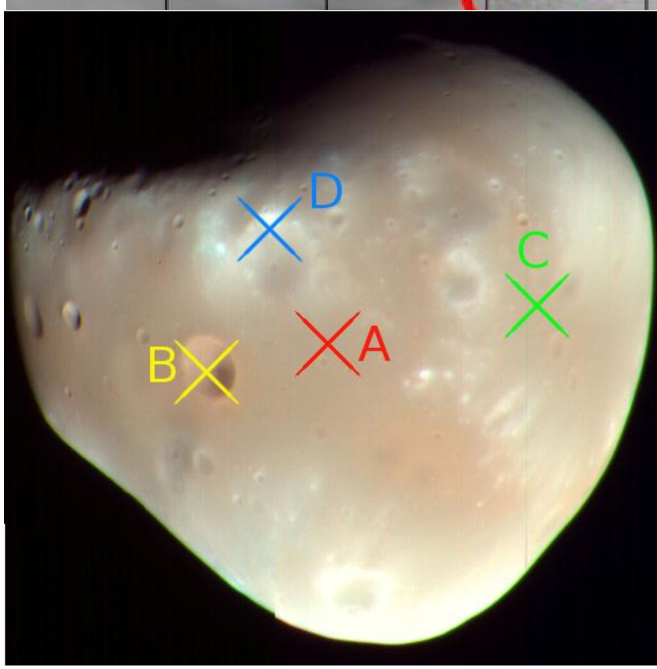
- Intermittent periods of occultations by Mars - crew will have to be trained to be autonomous.
- Number and duration of occultations can be reduced by more communication satellites in Mars orbit
- PE, DE, DPS and SEV will form "Martian System Network" for transmission of data from surface experiments on Phobos and Deimos.



Precursor Mission Landing Locations - Phobos

Location Index	Location Name	Agenda	Reason
A	Stickney Highlands	Impactor + spectrography, final location of Phobos Explorer	Prime candidate for first human mission landing spot, contains both red and blue material, good view of Mars
B	Stickney Crater	Impactor + Spectrography	Second location for human mission, will contain information about the origin of Phobos
C	North-Eastern Lowlands	Impactor +Spectrography	Backup location for human landing, neighborhood of Skyresh crater
D	South-Eastern Lowlands	Impactor + Spectrography	Backup location for human landing, very flat and low-lying, contains darker regolith





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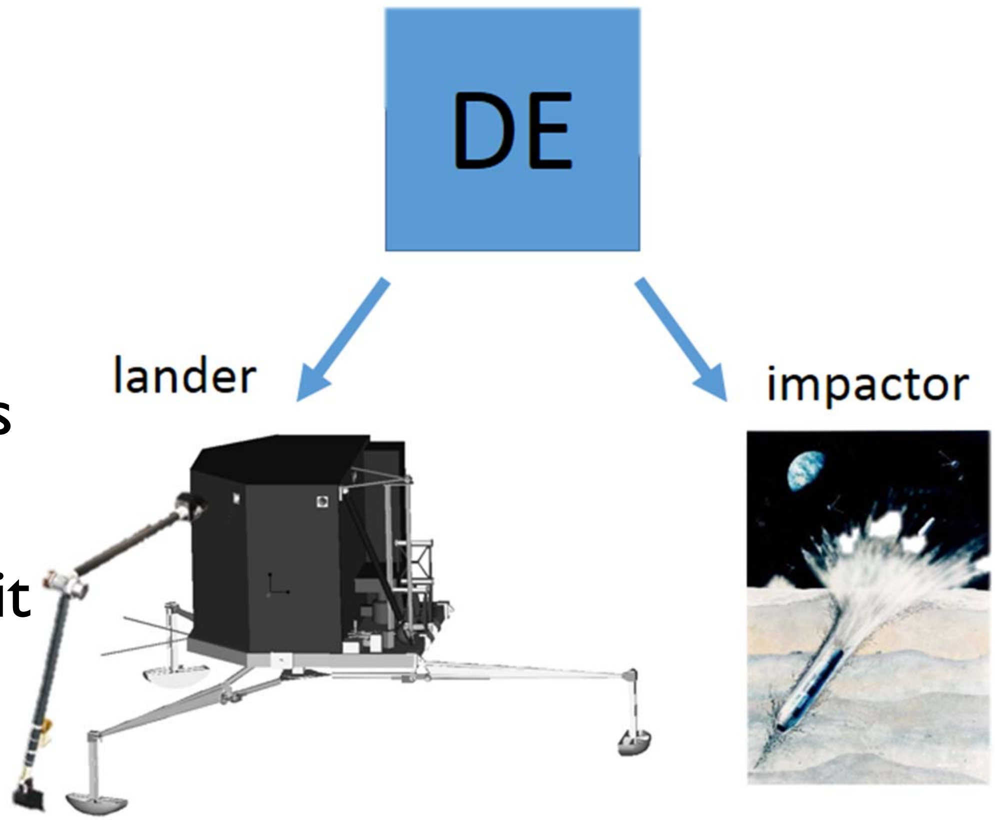
Precursor Mission Landing Locations - Deimos

Location Index	Location Name	Agenda	Reason
A	Central Highlands	Impactor + spectrography, final location of Deimos Explorer	Possibly rocky, high elevation, good view of Mars
B	Crater X	Impactor + Spectrography	Interior of a deep crater, filled in with dust and regolith
C	Eastern Flatlands	Impactor +Spectrography	Different color of regolith
D	Crater Y	Impactor + Spectrography	Edge of crater, contains white ejecta

Explorers (PE and DE)

- Orbit Mars near Phobos to release PE
- Lander lands, observes impacter experiments with DPS
- Orbit Mars near Deimos to release DE
- PDS moves to Mars orbit below Phobos

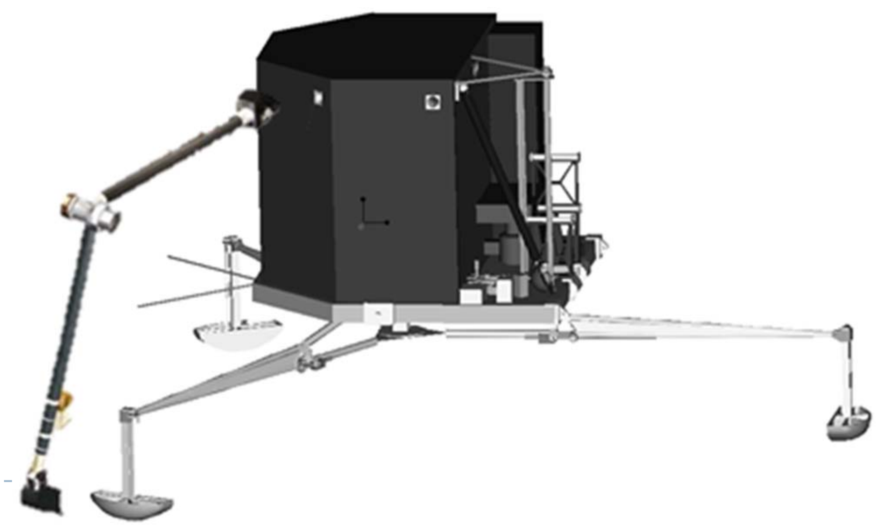


Impactors

- 4 penetrators (per explorer) plus penetrametors.
- Determine near-surface thermal properties and heat flux, density, and study the interior structure.
- Also provides an estimation of the density and cohesion of the surface material, and its particle size distribution

Landers

- Identical, to reduce cost
- 150 kg Philae-like lander (from Rosetta) with Phoenix-like sampling arm, RTG, and propulsion
- Philae uses harpoons to anchor.



SEV anchoring options

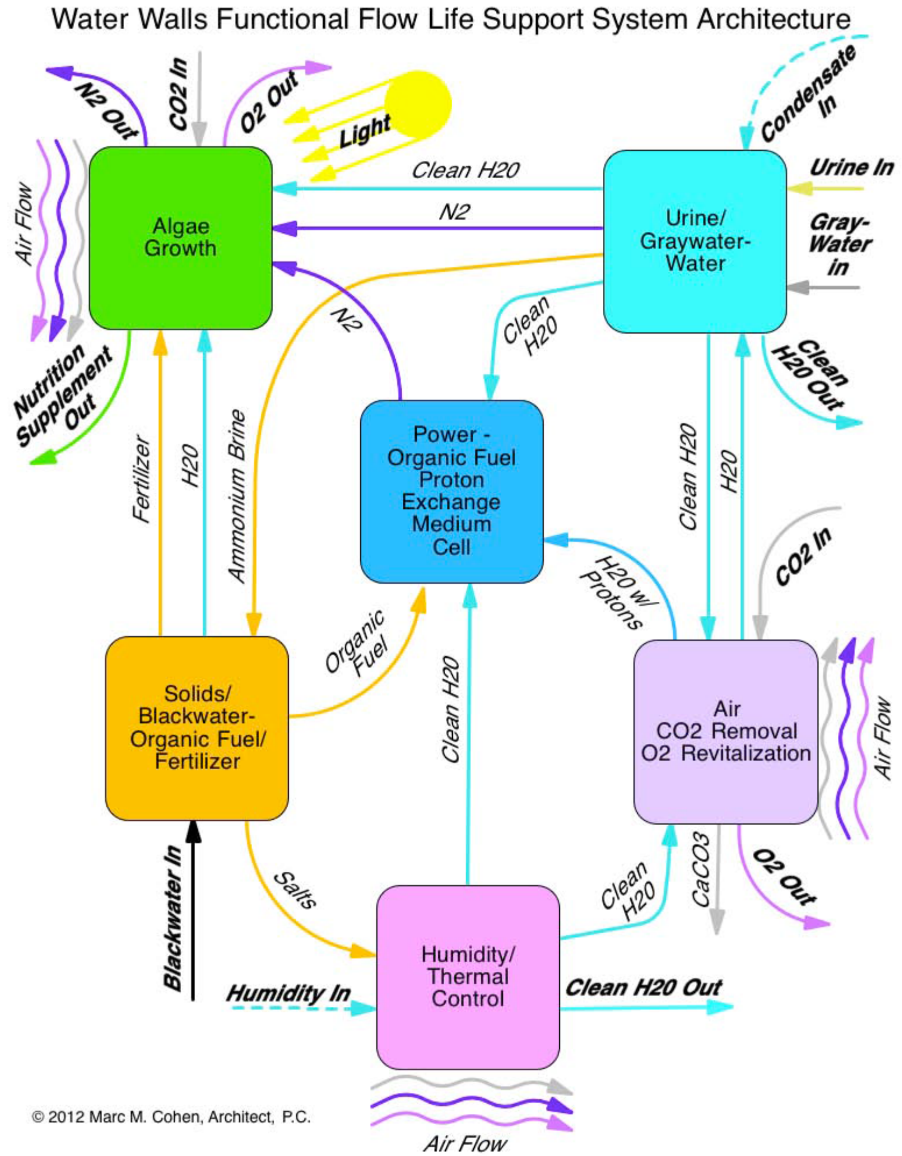
1) Unknown surface: thrusting into it, stationkeeping

2) Rock: harpoons, grappling hooks, microspines, adhesion, drills

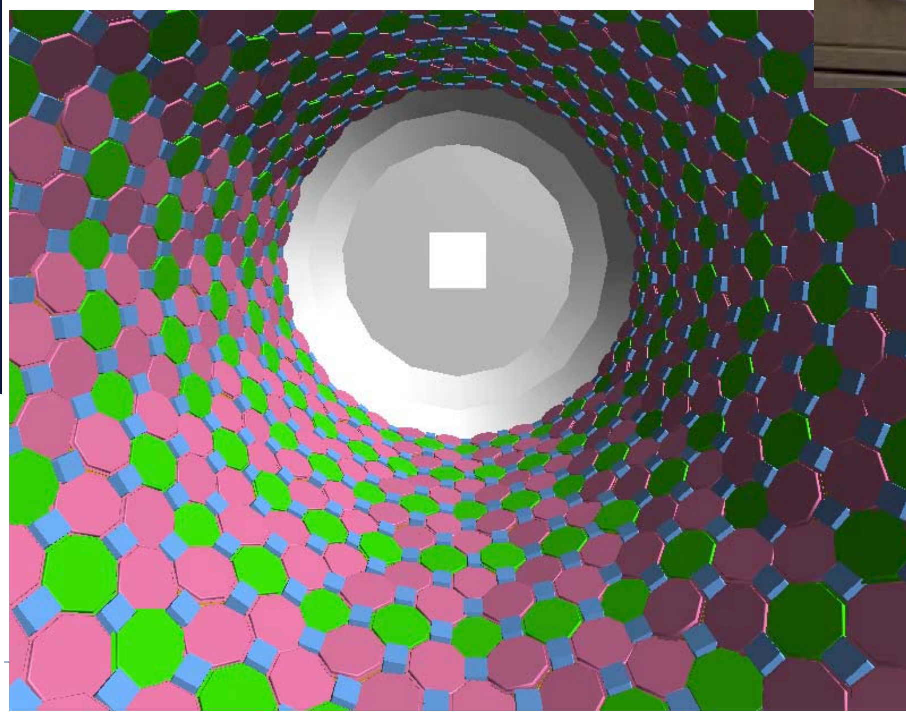
3) Regolith: earth anchors / stakes

Exact choice will depend on precursor mission's characterization of regolith.

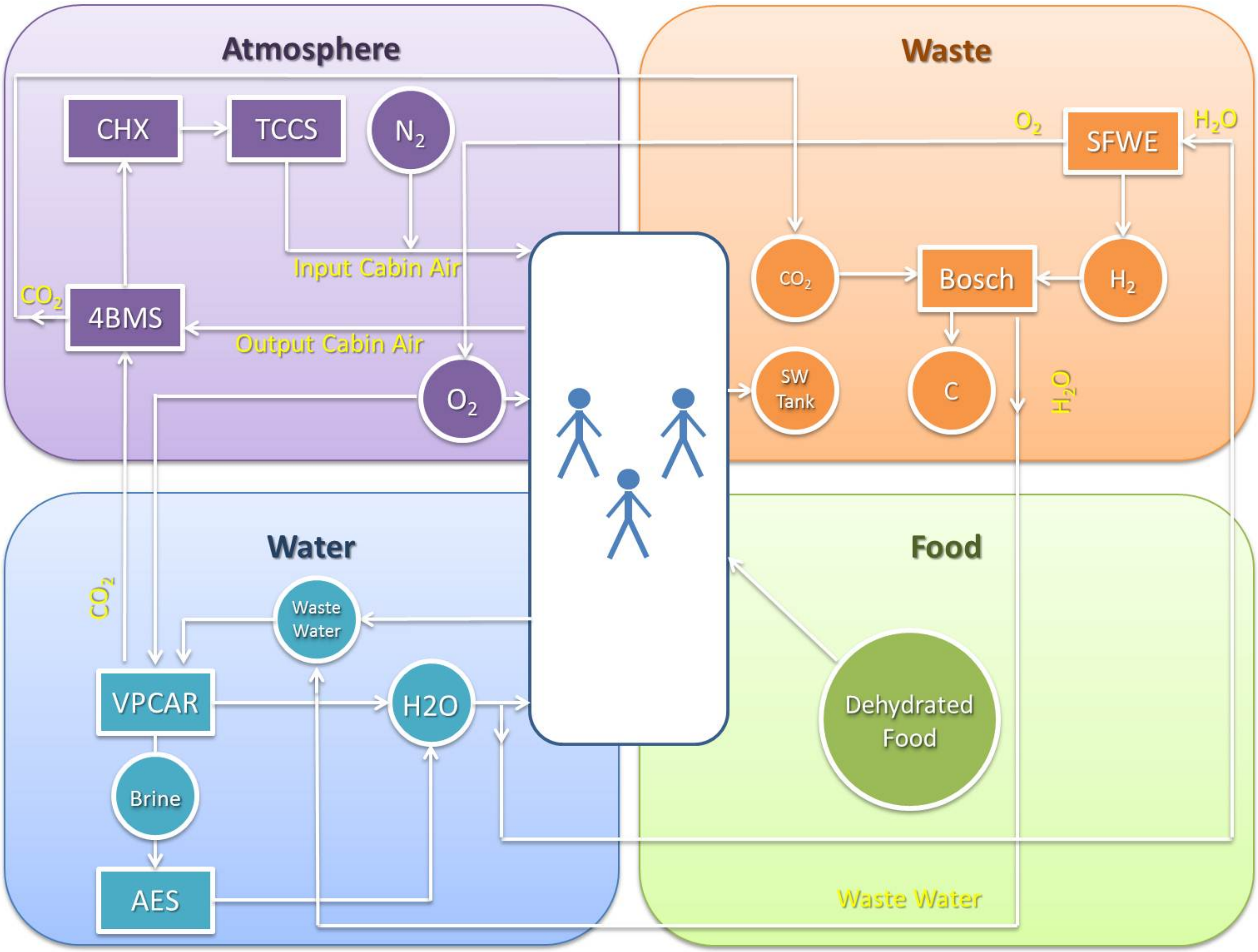
Water Walls


Water Walls Functional Flow Life Support System Architecture
N2 Out
CO2 In
O2 Out
Light
Condensate In
Clean H20
N2
Urine In
Gray-Water in
Air Flow
Algae Growth
Urine/ Graywater-Water
N2
Clean H20
Clean H20 Out
Nutrition Supplement Out
Fertilizer
H20
Ammonium Brine
Power - Organic Fuel Proton Exchange Medium Cell
Clean H20
H20
H20 w/ Protons
CO2 In
Organic Fuel
Clean H20
Solids/ Blackwater-Organic Fuel/ Fertilizer
Air CO2 Removal O2 Revitalization
Air Flow
Salts
Clean H20
CaCO3
O2 Out
Blackwater In
Humidity In
Humidity/ Thermal Control
Clean H20 Out
Air Flow

Water Walls



DSH Primary ECLSS

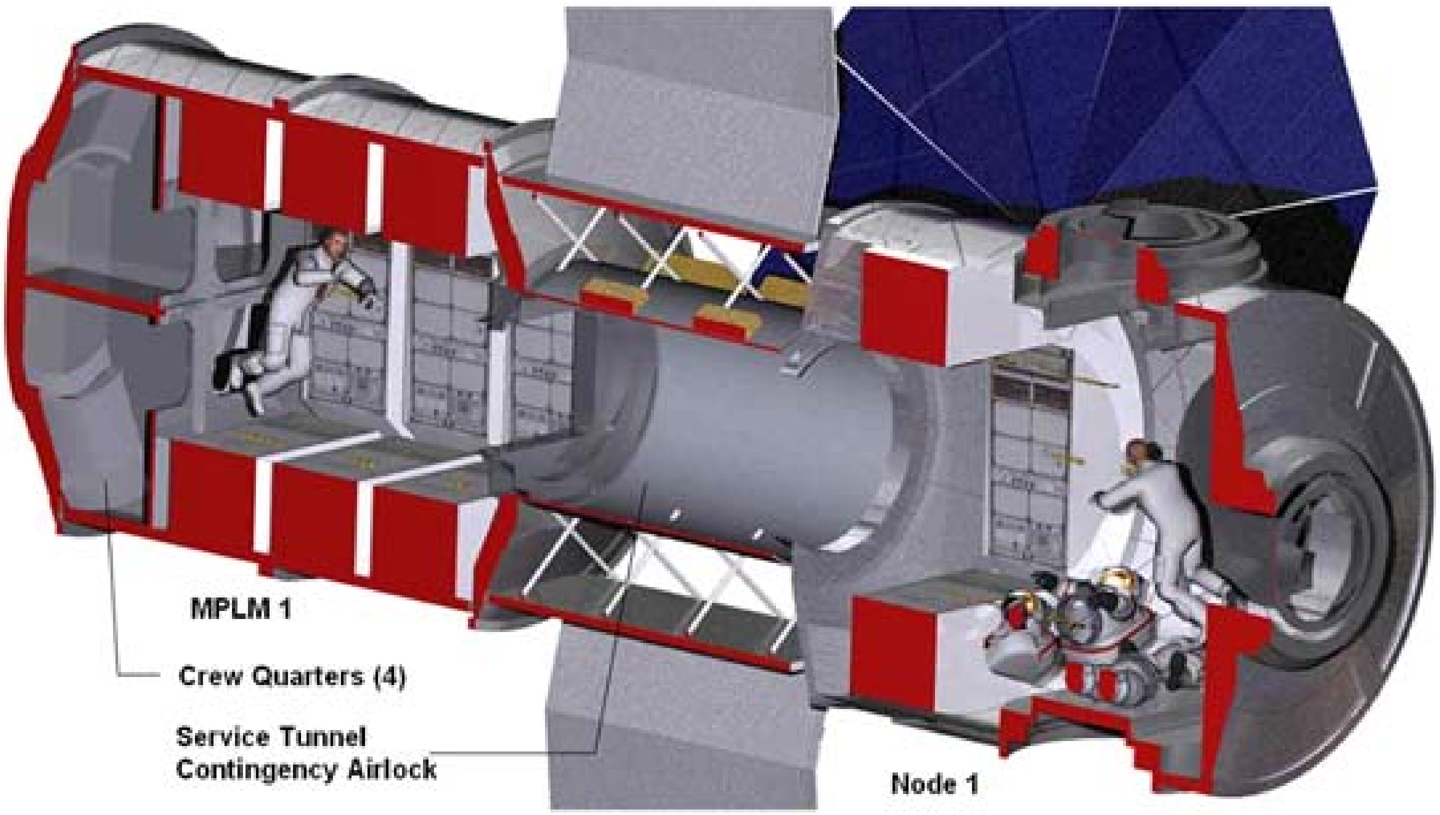


DSH Primary ECLSS

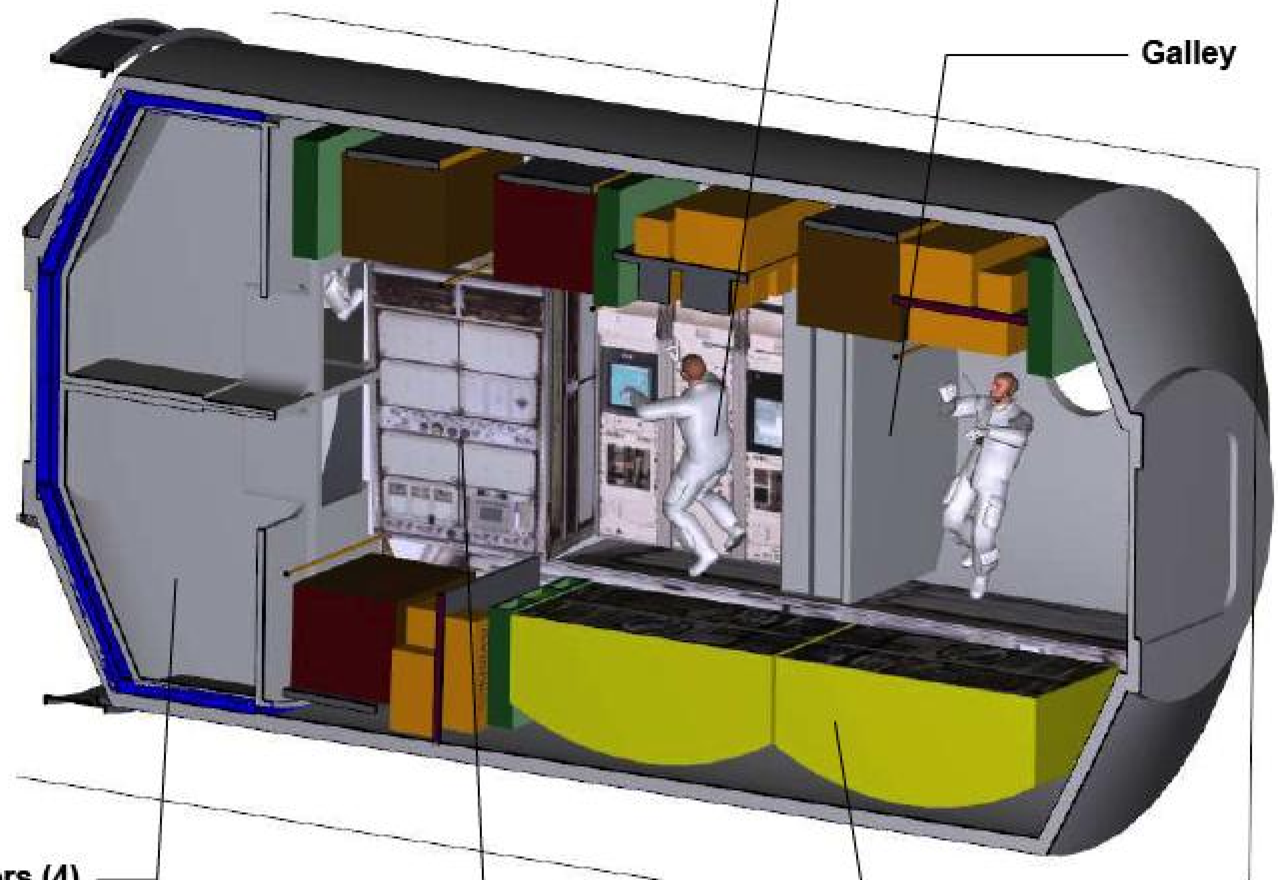
Function	Hardware	Mass (kg)
Carbon Dioxide Removal	4-Bed Molecular Sieve (4BMS)	120
Oxygen Generation	Statif Feed Water Electrolysis (SFWE)	100
Temperature and Humidity Control	Condensing Heat Exchanger (CHX)	100
Trace Contaminant Control	Trace Contaminant Control (TCC)	100
Carbon Dioxide Reduction	Bosch	102
Waste Water Treatment, Urine Pretreatment	Vapor Phase Catalytic Ammonia Removal (VPCAR)	340
Brine Treatment	AES	178
Food Packaging	15% Food Mass	138.79
Clothing	-	442.5
ECLSS Storage Tanks	High pressure storage tanks for gases	4356.5
Air Monitoring System	ANITA 2	27
Fire Suppression	Water droplet fire extinguisher (16kg per unit)	48
Total Dry Mass	-	**6052.79**

ECLSS Consumable	Mass (kg)	Comments/Rationale
Dehydrated food	925 (0.62 kg/p/d)	[BVAD 2004]
O2	150	Estimated from ELISSA simulation to provide crew with 2.8 kg of oxygen per day and maintain cabin atmosphere
Potable H2O	500	Estimated from ELISSA simulation to provide crew with 2.8 kg of oxygen per day and maintain ECLSS systems
Hygiene H2O	0	This water will come from the Water Walls system; estimates for hygiene H2O are 0.4 kg/p/d [HIDH]
H2	15	Estimated from ELISSA simulation to maintain ECLSS systems and cabin atmosphere
N2	290	Estimated from ELISSA simulation to maintain ECLSS systems and cabin atmosphere
Total Wet Mass (kg)	**1880.25**	

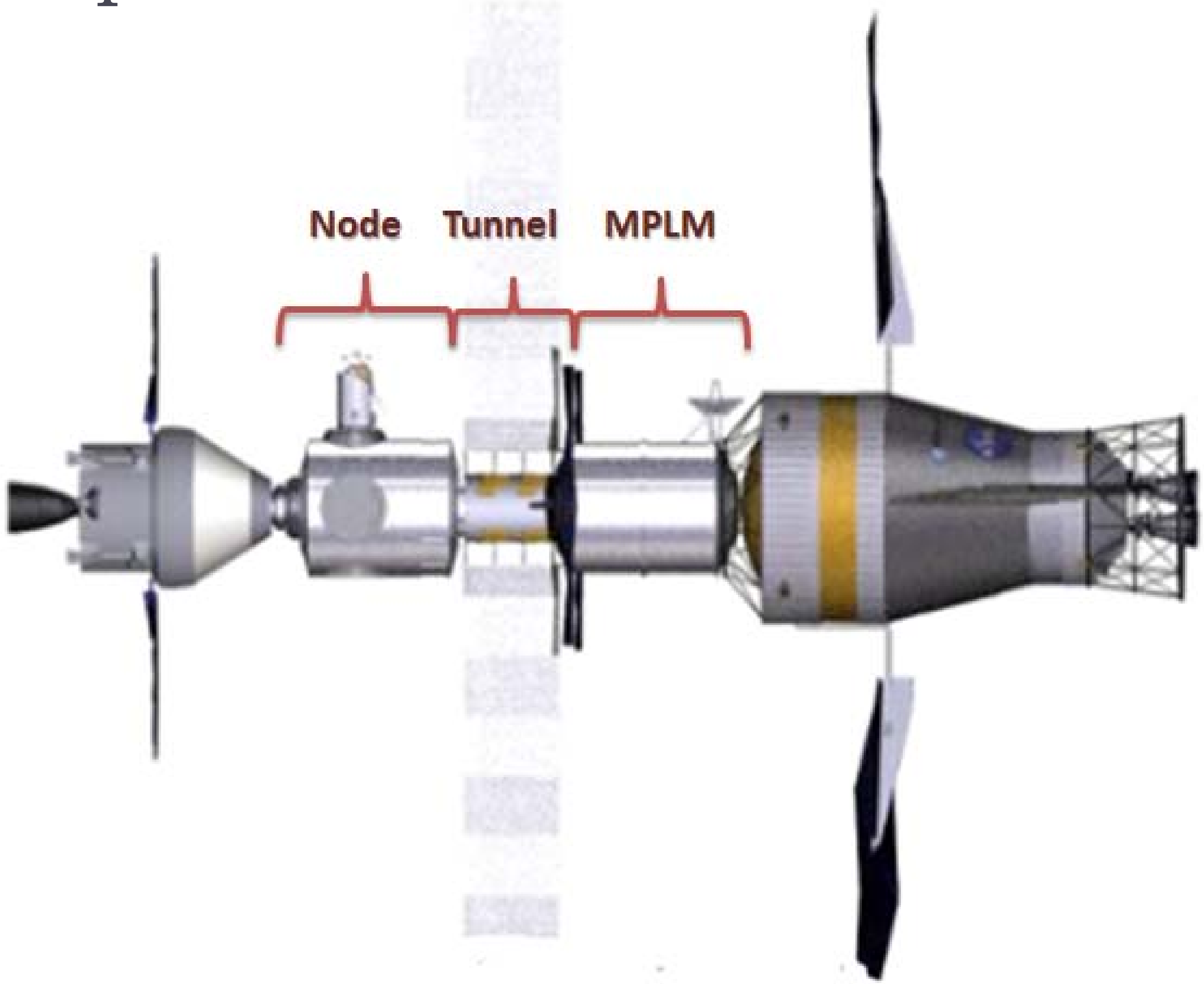
Deep Space Habitat



Deep Space Habitat



Deep Space Habitat



Electrical Power System (EPS)

- Considered Technologies
  - Photovoltaic converters
  - Solardynamic converters
  - Nuclear power plants
  - Radioisotope Thermoelectric Generator (RTG)

  - Li-Ion secondary batteries
  - Regenerative Fuel Cell System (RFCS)

Electrical Power System

- Major assumptions
  - Solar energy sufficient for missions to the Martian system (no need of nuclear power)
  - Photovoltaic superior to solardynamic (TRL)
  - Photovoltaic converters based on Ultraflex solar panel technology of the MPCV
  - Energy storage subsystem synergistically linked to life support system sharing H_2O, H_2 and O_2 infrastructure

Electrical Power System

- EPS bugets (including a 15% margin)

Characteristic	DSH		SEV	
EPS power requirements	12.6	kW	4.64	kW
Solar panel areas	134	m^2	50	m^2
Solar panel masses	163	kg	60	kg
Electrical power storage masses	290	kg	107	kg
Total EPS masses	1017	kg	315	kg

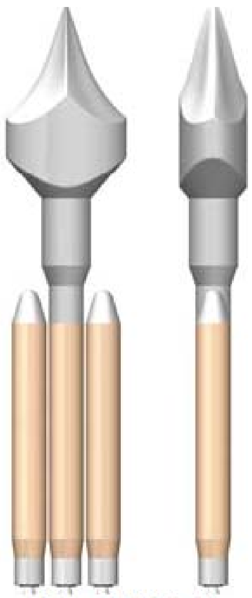
Thermal Control System (TCS)

- Major assumptions
  - Worst case during assambly in LEO
  - Thermal loads coming from:
    - Direct sunlight irradiation
    - Sunlight reflected from Earth
    - IR radiation from Earth
    - 100% electrical power to get rid off
  - Liquid cooling loops having radiators directly attached to the surface of the modules

Thermal Control System

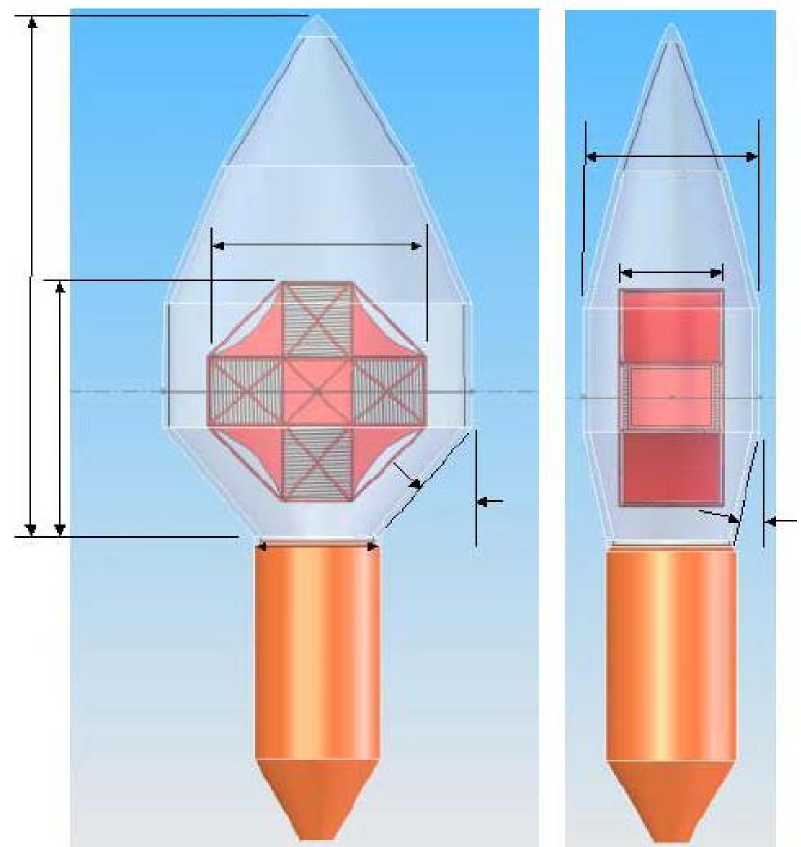
- TCS budgets (including a 15% margin)

Characteristic	DSH		SEV	
Radiator areas	81	m^2	26	m^2
Liquid radiator system mass budget	564	kg	185	kg
Liquid radiator system power budget	290	W	107	W



Atlas V HLV with large asymmetric fairing

	5.4m Atlas V HLV PLF	Large Asymmetric PLF
Static payload envelope (m)	ø4.6 x 12.2h	9.3w x 10h x 4.3d
Available payload volume (m^3)	203	400
Fairing Length (m)	26.5	29.2
Construction	Composite sandwich	Composite sandwich
Mass (kg)	4,394	5,965



Source: ATA Engineering, Inc 2010

	Asaph mothership delta-v Summary	
Maneuver #	Description	delta-v
Maneuver 1	Delta-v to place mothership on hyperbolic trajectory	3.5 km/s
Maneuver 2	Delta-v for Mars orbit insertion (MOI)	4.7 km/s
Maneuver 5	Burn at apoapsis when Phobos-HEV phase difference is 180° with plane change of 11.6° from ecliptic to 1.1° with respect to Mars' equatorial plane	0.6 km/s
Maneuver 6	Phobos trailing orbit insertion for mothership	0.3 km/s
Maneuver 7	Phobos trailing orbit departure for mothership	0.3 km/s
Maneuver 8	Burn at apoapsis to prepare for escape trajectory	0.2 km/s
Maneuver 9	Delta-v for Mars sphere of influence escape for return to Earth	3.7 km/s
	Mothership Total Delta-V	13.3 km/s

	Asaph SEV delta-v Summary	
Maneuver #	Description	delta-v
Maneuver 3	Burn at apoapsis when Phobos-HEV phase difference is 180° with plane change of 11.6° from ecliptic to 1.1° with respect to Mars' equatorial plane	0.6 km/s
Maneuver 4	Phobos trailing orbit insertion for astronaut EVA	0.3 km/s
	SEV Total Delta-V	0.9 km/s

Predeploy

Unit	Mass (t)	Power (kW)	comments		Isp
SEV	30				
Science equipment on SEV	0.4				
DE	0.1				
DPS	0.1				
Equipment left on Phobos	0.4				
Solar panels	Emil				
SEP engine	6				3000
Fuel	Paul		Electric propellant		
Samples	0.1		Only return trip		
PPM			Phobos Propulsion Module		
Fuel	Paul				
Oxidizer	Paul				
Total	37.1				

Cargo

Unit	Mass (t)	Power (kW)	comments		
DSH	45		dry mass		
Supplies	5		for a 500 day mission		
CRYO1	6				325
Fuel	Paul		for cryo stage		
Oxidizer	Paul		for cryo stage		
CRYO2	6				325
Fuel	Paul		for cryo stage		
Oxidizer	Paul		for cryo stage		
SEP stage	15.8				3000
Fuel	Paul		Electric propellant		
Solar panels	0.5				
Comm subsystem	0.05				
Total	78.35				

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Unit	Mass (t)	Power (kW)	comments
Crew module	10		dry mass
Service module	20		
Total	30		