Gemini Mars International Design Competition

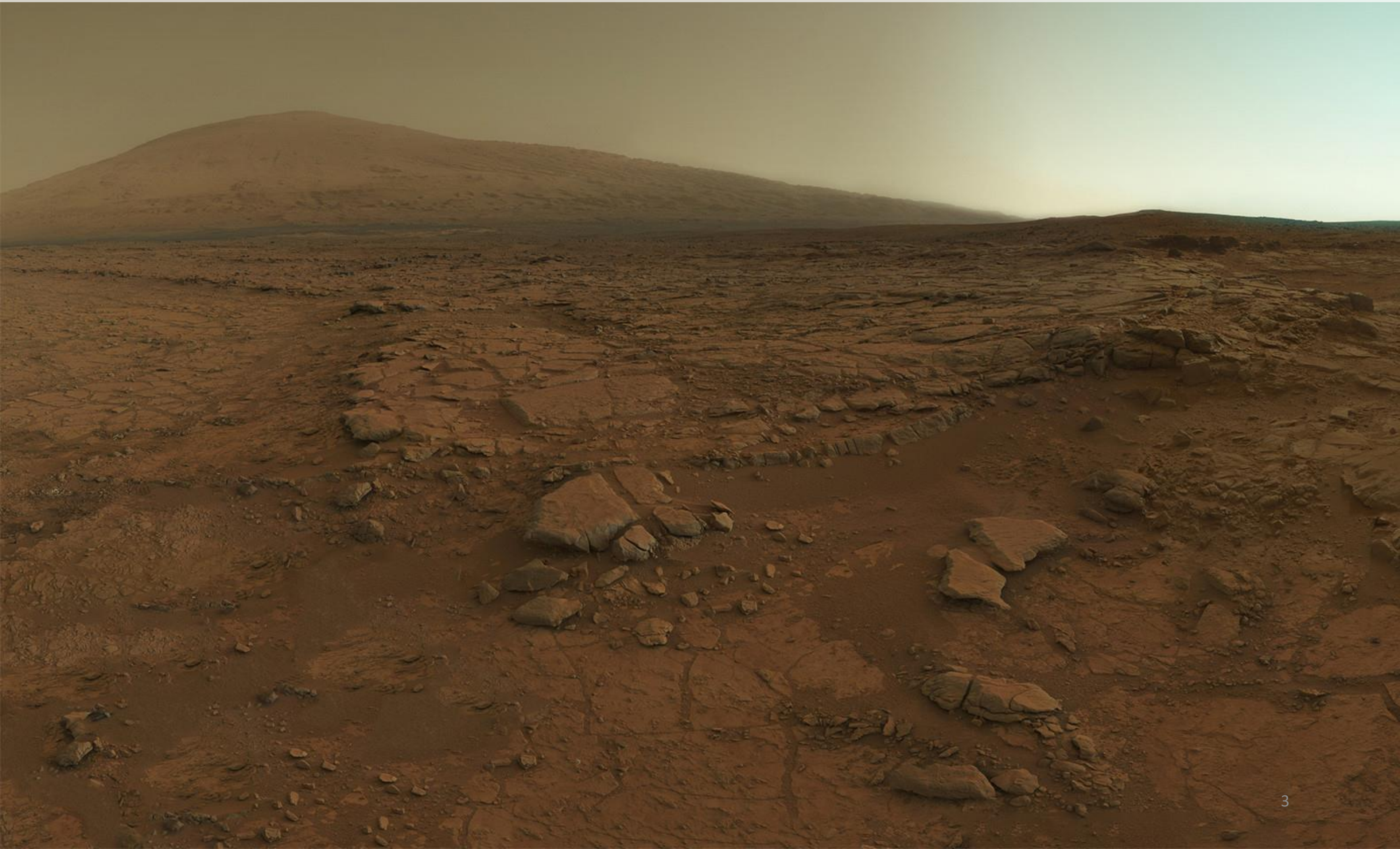
19^{th} Annual Mars Society Convention

24^{th} September 2016

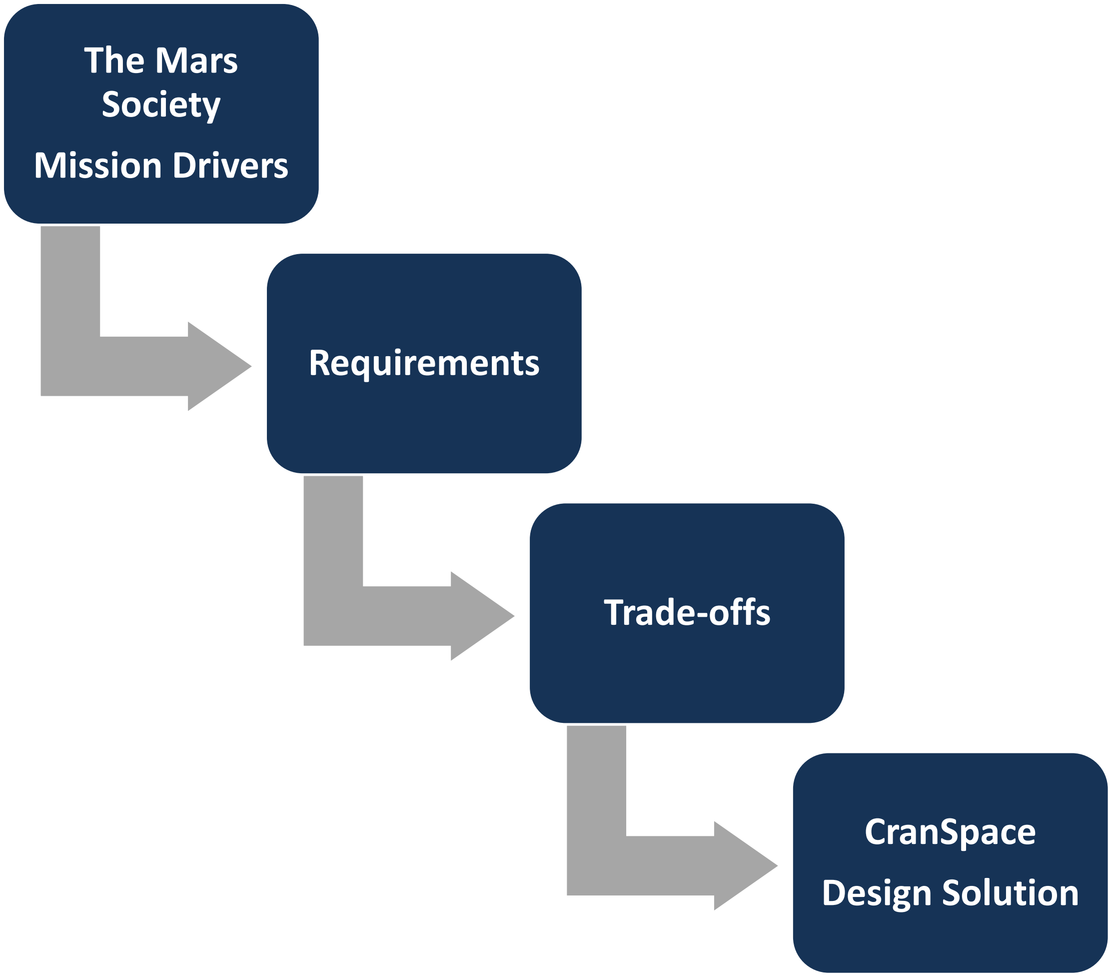
Presentation Overview

- Mission Outline
- Introducing the CranSpace Solution
- Trajectory
- Journey to Mars (and back)
  - Launch
  - Venus Fly-By
  - Mars Fly-By
  - Earth Re-Entry
- Mission Cost
- Summary

“To design a **two-person flyby** mission to **Mars**, to be launched before the end of the **2024**, to recapture the imagination of the public and give direction to the U.S. human spaceflight program.”



Project Approach



Payload to LEO

- TMI Payload:
  41560 kg

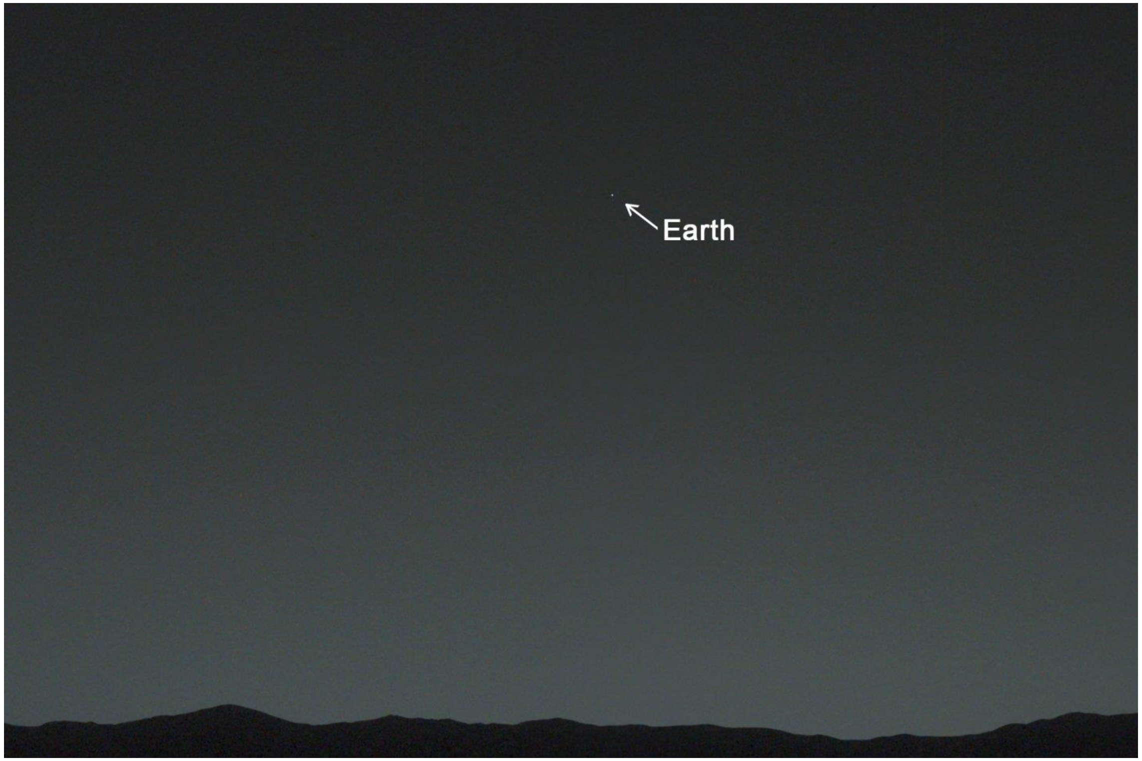
- Required Propellant:
  89300 kg

- Overall Mass:
  146600 kg

http://blogs.nasa.gov/Rocketology/wp-content/uploads/sites/251/2015/07/SLS70mtLaunch_LowAngle_Landscape-Screen.jpg

Longest Human Duration in Space

- Furthest Distance from Earth: 78 million km
- Mission Duration: 580 days

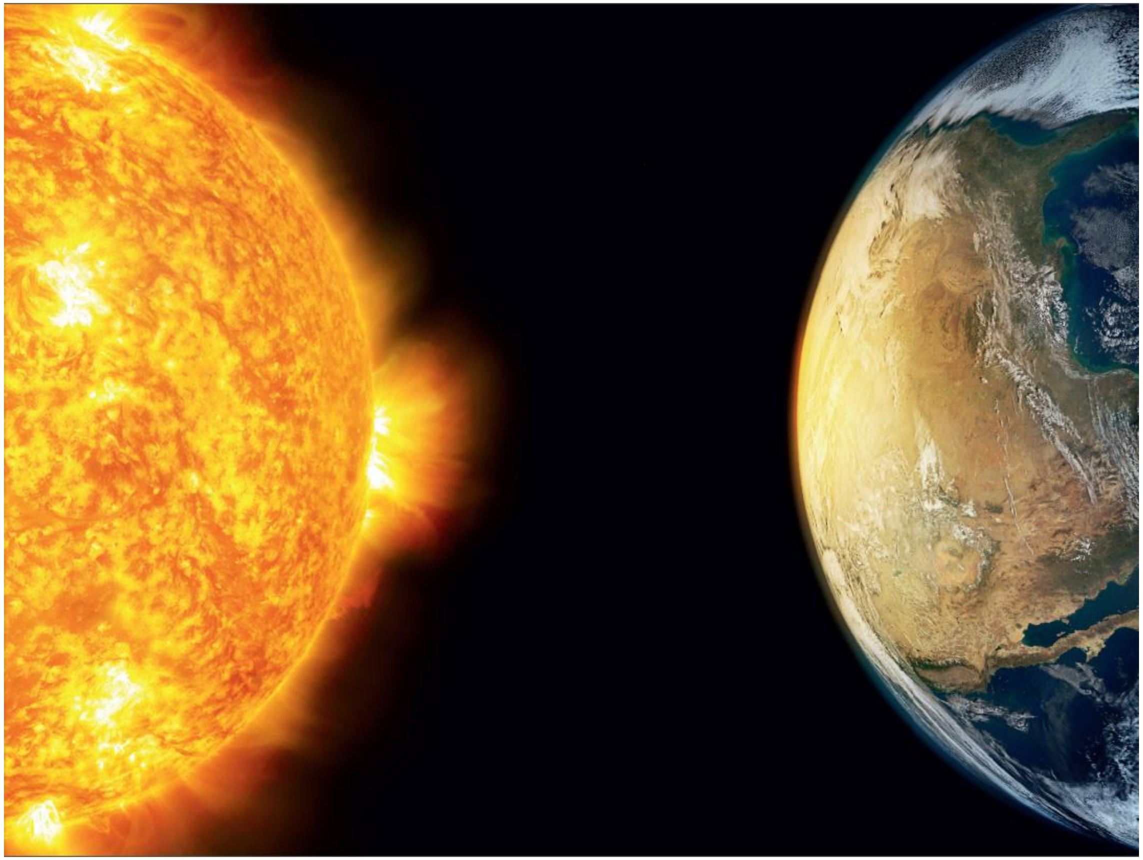


http://photojournal.jpl.nasa.gov/jpeg/PIA17936.jpg

Solar Radiation

- Solar maximum occurs in 2024

- Max. radiation allowed
  Male: 3.25 Sv
  Female: 2.5 Sv



http://cdn.phys.org/newman/gfx/news/hires/2015/25-researcherss.jpg

Mission Required Consumables

- Required Consumables (No Recycling)

  Water: 5450 kg

  Oxygen: 1000 kg

  Food: 755 kg

https://i.ytimg.com/vi/6vVle67Tfjc/maxresdefault.jpg

Issues Away from Earth

https://upload.wikimedia.org/wikipedia/commons/a/ac/Apollo_13-insignia.png
https://i.ytimg.com/vi/1WHzyzlLABc/maxresdefault.jpg

Top Level Systems Requirements

RQ01	Capability of **supporting two crew** for the entire mission
RQ02	Compatibility with **existing launchers** and spacecraft
RQ03	Hypersonic re-entry shall not exceed spacecraft and crew capabilities
RQ04	The spacecraft shall provide sufficient **radiation protection** for a maximum extended-period dose of **0.730 Sv**
RQ05	No critical single point failures in the life-support system
RQ06	Mission shall be completed by **end of 2024**

Design and Risk Philosophy

Technology **heritage** is the backbone of the CranSpace design philosophy.

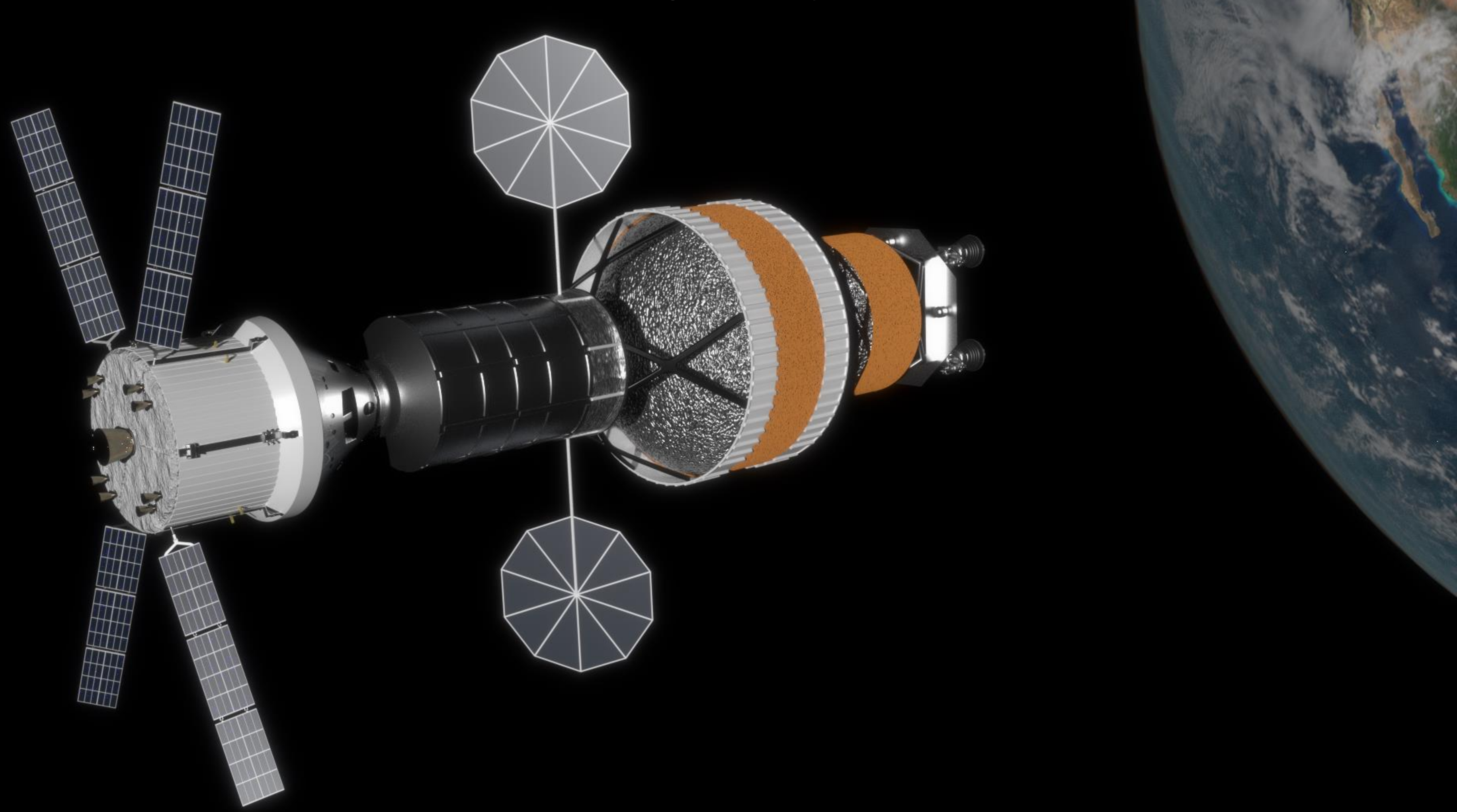
- Reduces implementation risks
  - Less time spent on R&D
  - Less uncertainty in margins

- Reduces mission risks
  - Draws on lessons learnt
  - Targeted mitigation for known issues

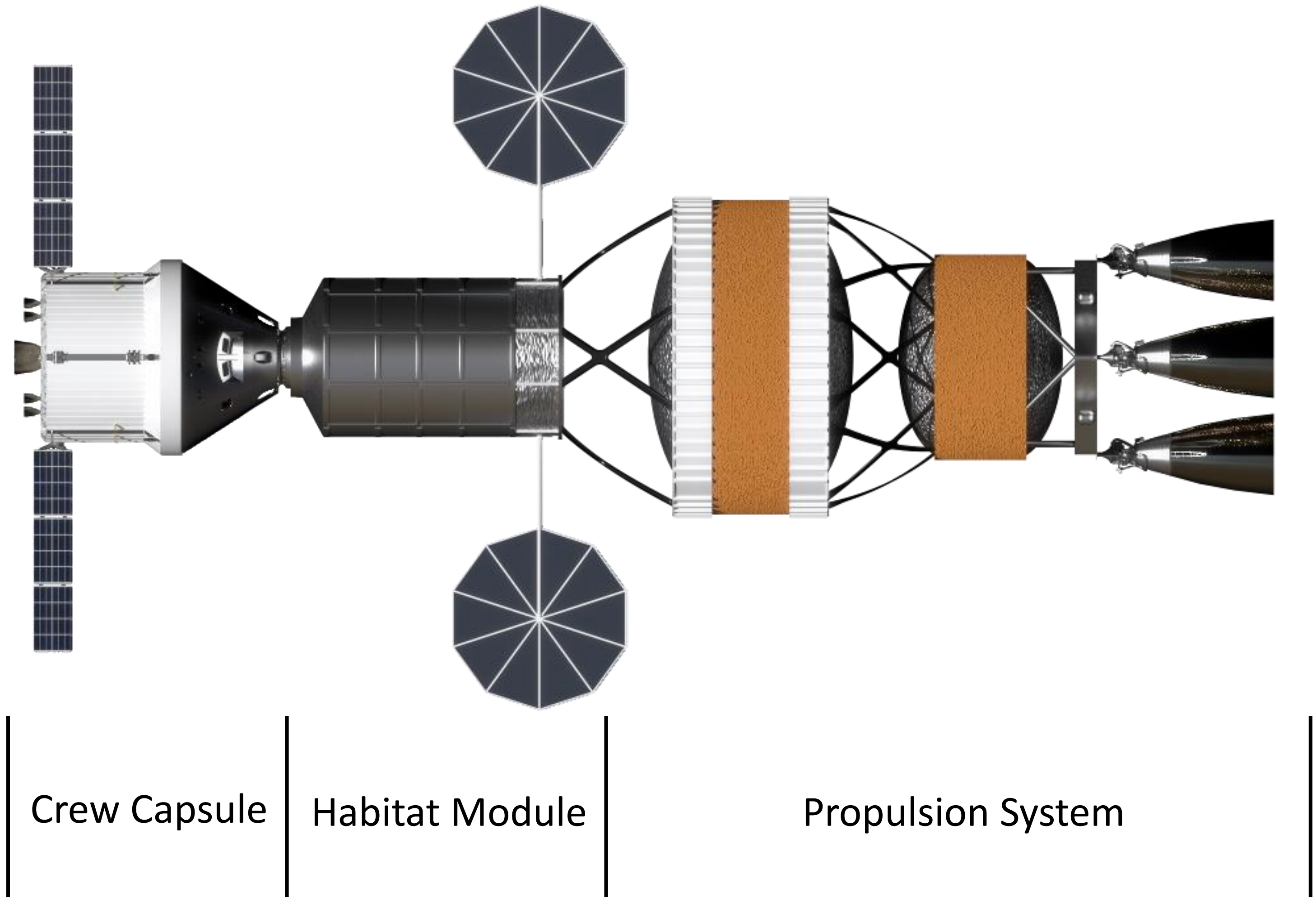
Emphasis on **redundancy** to reduce critical single point failures

CranSpace Design Solution - TOTEM

Transfer-vehicle for Observation, Testing and Exploration of Mars



The Spacecraft
TOTEM



Ascent/Re-entry Capsule

Driving Requirements

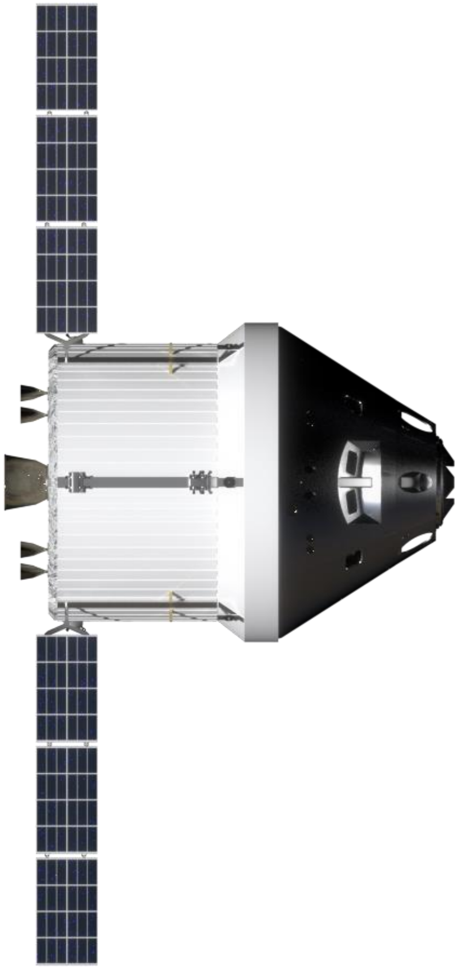
- Available for 2021 launch
- Rated for interplanetary travel
- Capable of hypersonic re-entry

Trade-off Parameters

- Mass
- Technology Readiness Level (TRL)
- Design uncertainty
- Service module capabilities
- Window size

Solution

- Orion capsule
- Interior augmentations e.g. removing spare seats



Habitat Module

Driving Requirements

- Available for 2021 launch
- Required habitable living volume above **5.1m³/CM**
- Protection from radiation

Trade-off Parameters

- Design heritage
- Pressurised volume
- Interface with capsule
- Interior re-design

Solution

- Multi-Purpose Logistics Module (MPLM)
- Add internal radiation shielding / sleep chamber
- Service module heritage from Cygnus

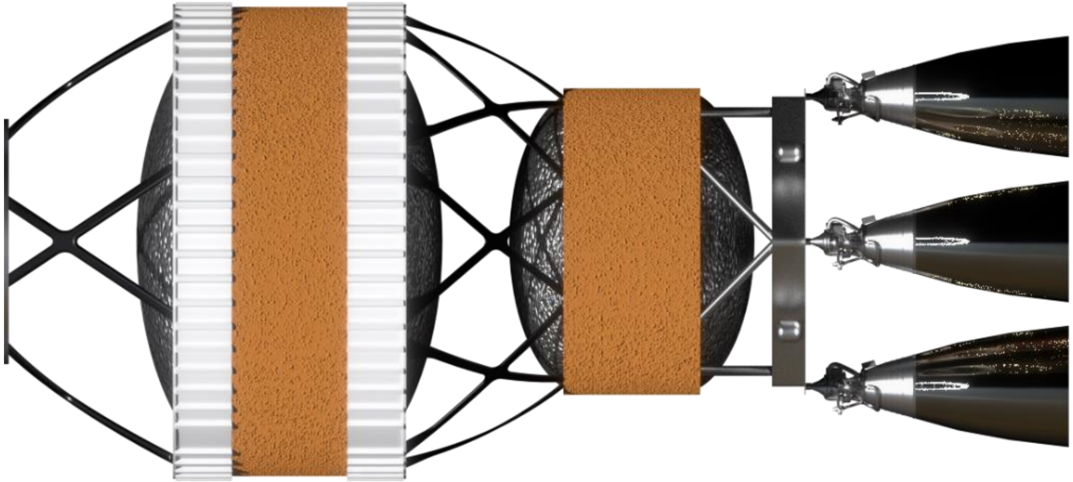
Propulsion System

Driving Requirements

- Ready for 2021 launch
- Required Delta V
- Existing propulsion system

Trade-off Parameters

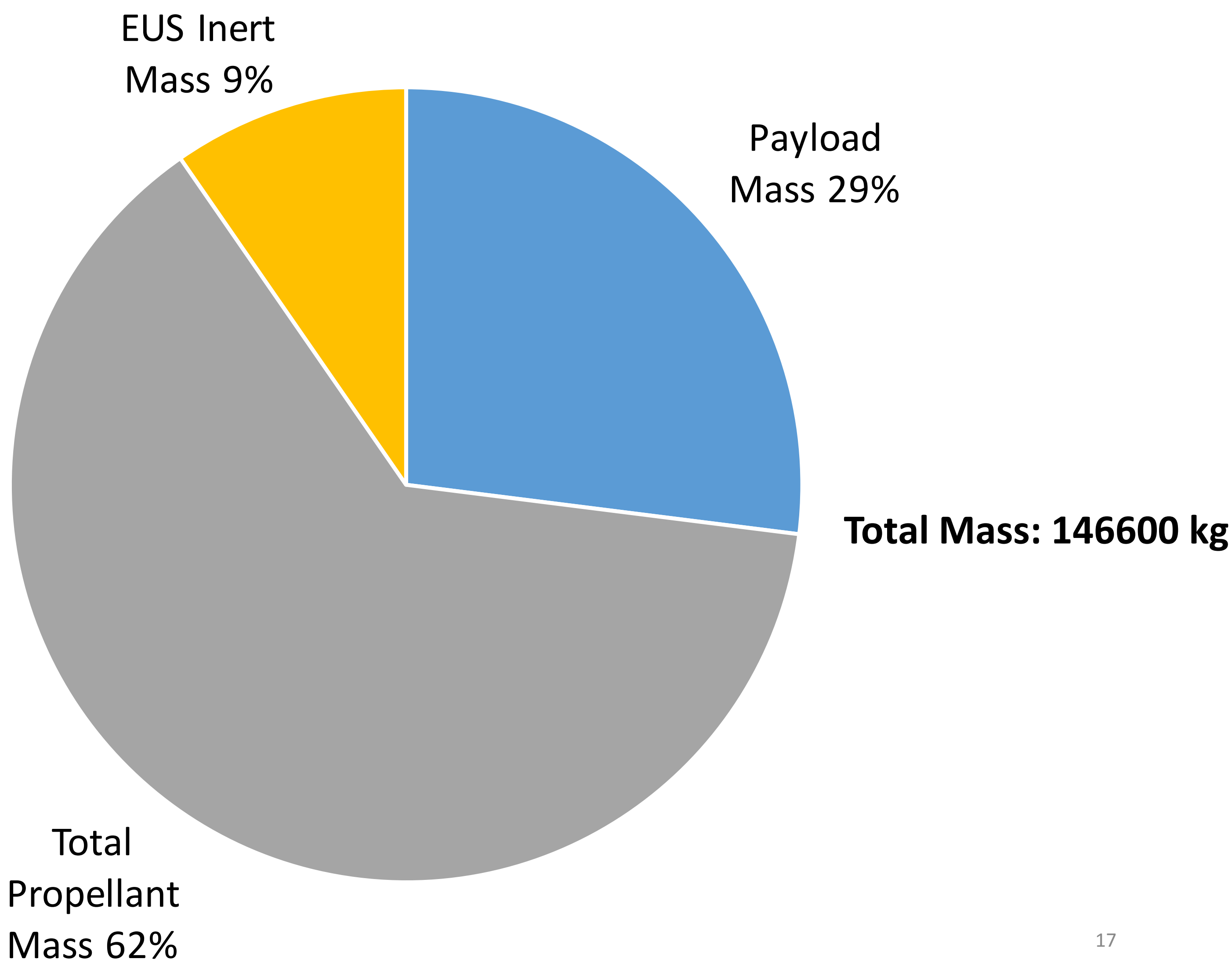
- Configuration simplicity
- Launcher interface
- No. of required launches
- Delta V margin



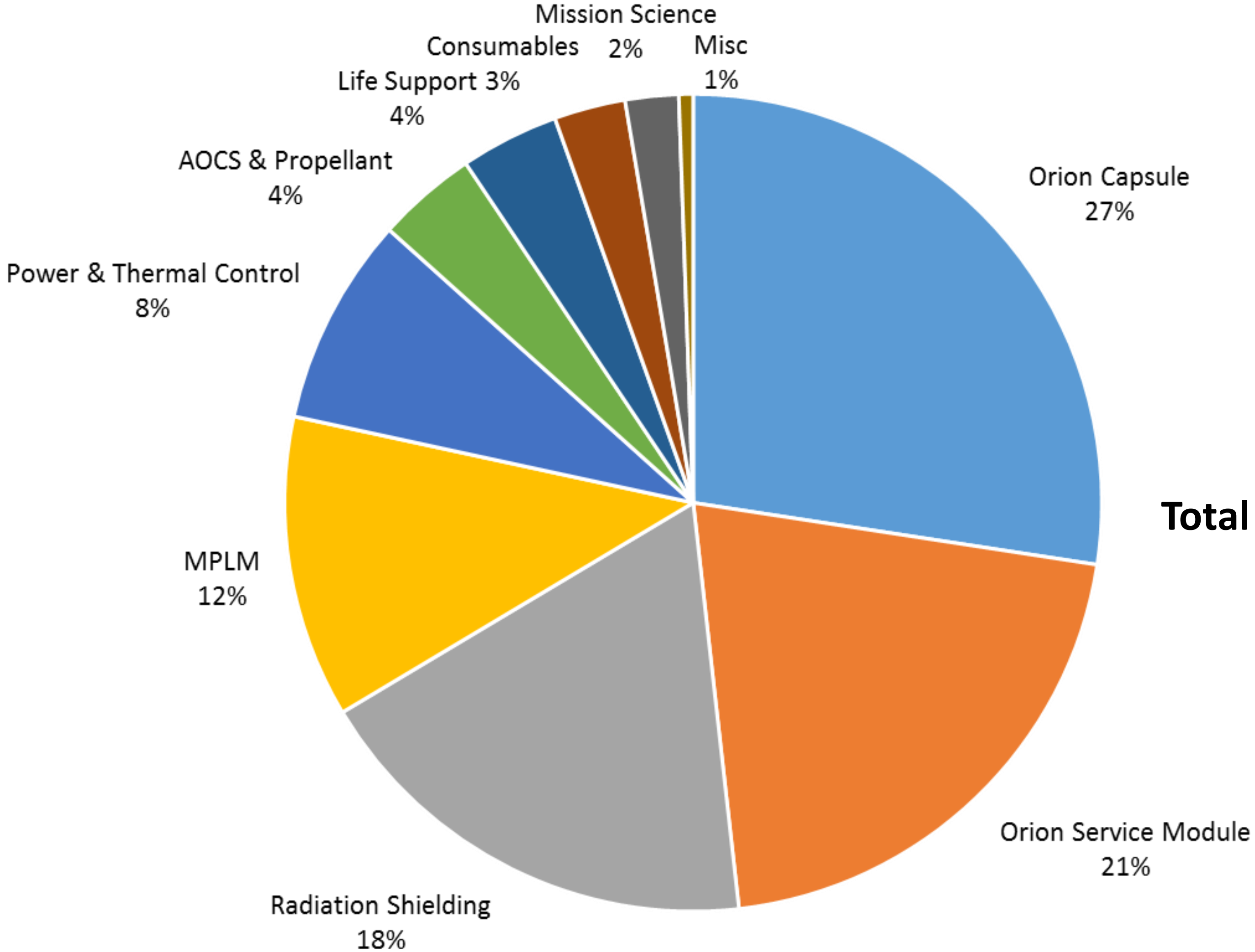
Solution

- SLS Exploration Upper Stage (EUS)
- Custom interface to habitat module

Spacecraft Mass Breakdown
LEO



Spacecraft Mass Breakdown
Payload



Total Mass: 41560 kg

Trajectory

Driving Requirements

- Mission length **under 600 days**
- Launch after 2021
- Complete mission by end of 2024

Trade-off parameters

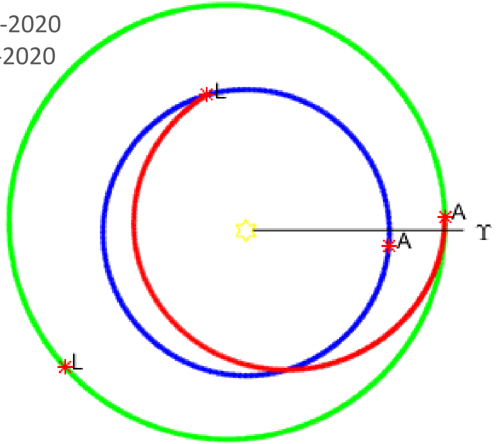
- Delta V
- Mission length
- Mission launch
- Solar maximum

Methodology

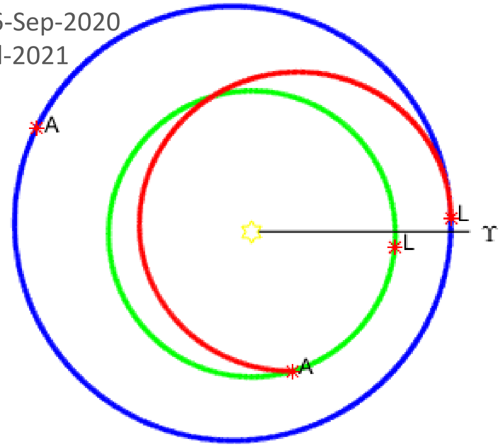
- Optimisation algorithm using patched conics, Lambert arcs and Lagrange multipliers
- Suggested **EVME** trajectory included in trade-off

Option

DV: 6.17 km/s
Launch Earth: 07-Jan-2020
Arrival Mars: 16-Sep-2020

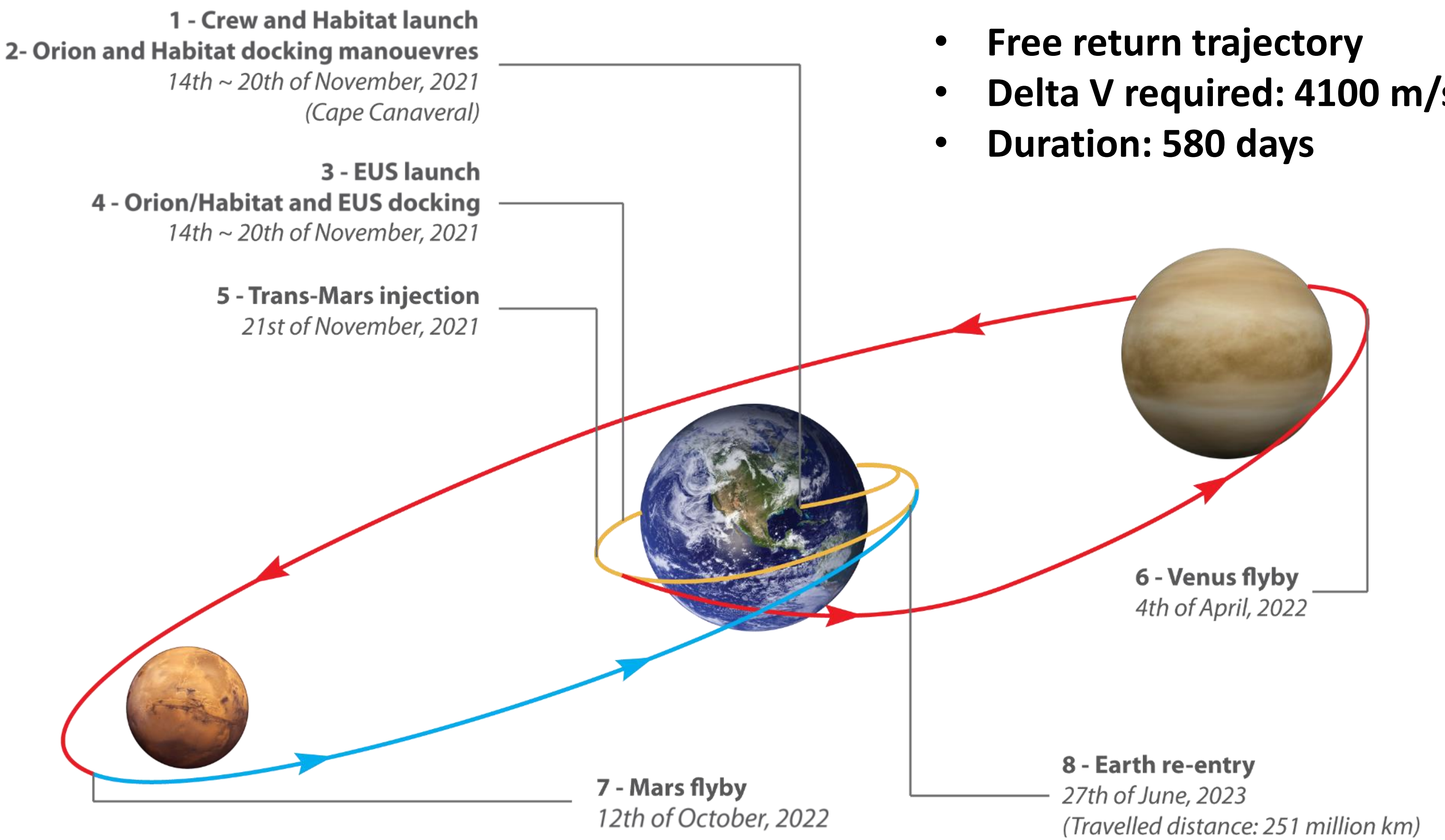


DV: 0.00 km/s
Departure Mars: 16-Sep-2020
Arrival Earth: 08-Jul-2021



Trajectory Solution

- **Free return trajectory**
- **Delta V required: 4100 m/s**
- **Duration: 580 days**



*Distances and sizes not for scale

Launch Configuration

Driving Requirements

- Available for 2021 launch
- Existing or in-development launchers

Trade-off parameters:

- Cost
- Risk
- Design heritage
- Availability

Solution:

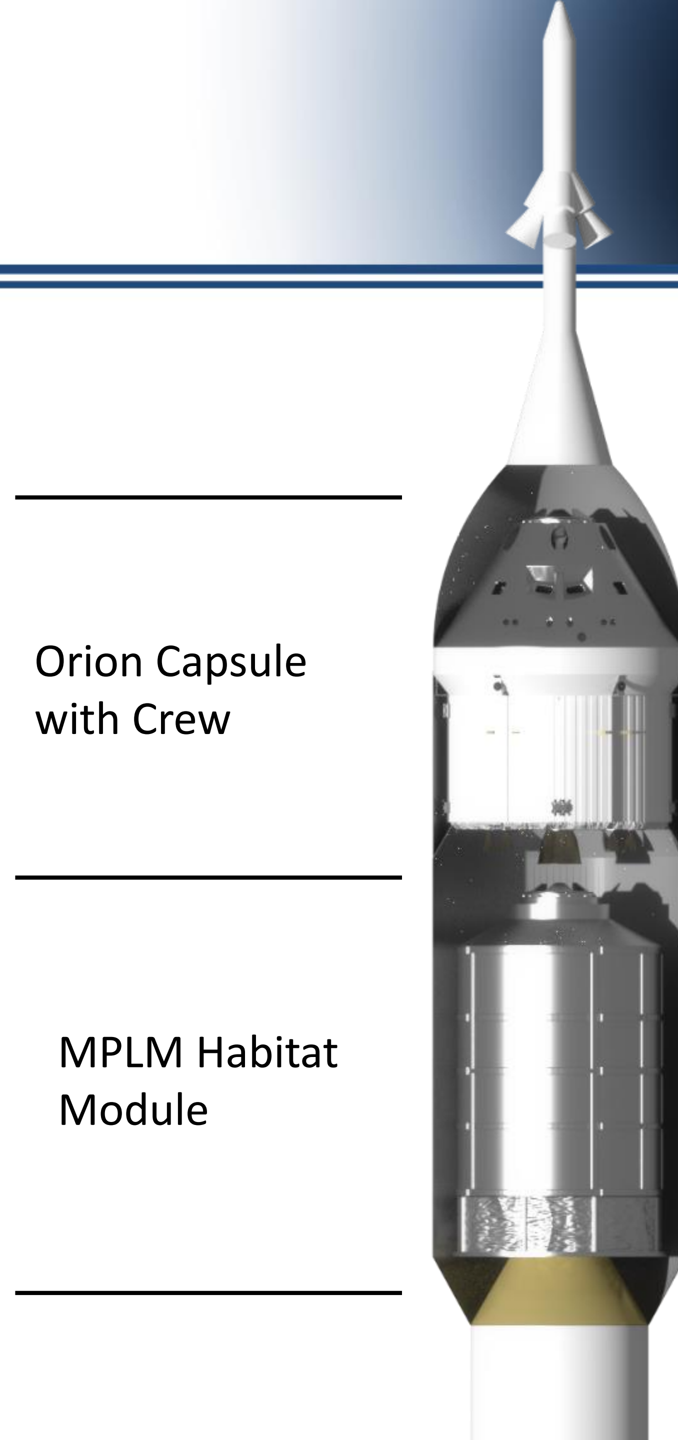
- **Two launches** (SLS 1B and Falcon Heavy) from Cape Canaveral
- Reduction in LEO Rendezvous and docking
- Cost effective

Launch I
Falcon Heavy

- Launch date: 14th November 2021
- Payload to LEO: 41600 kg
- Custom fairing required

Rationale:

- Human rated
- Flight heritage by 2021

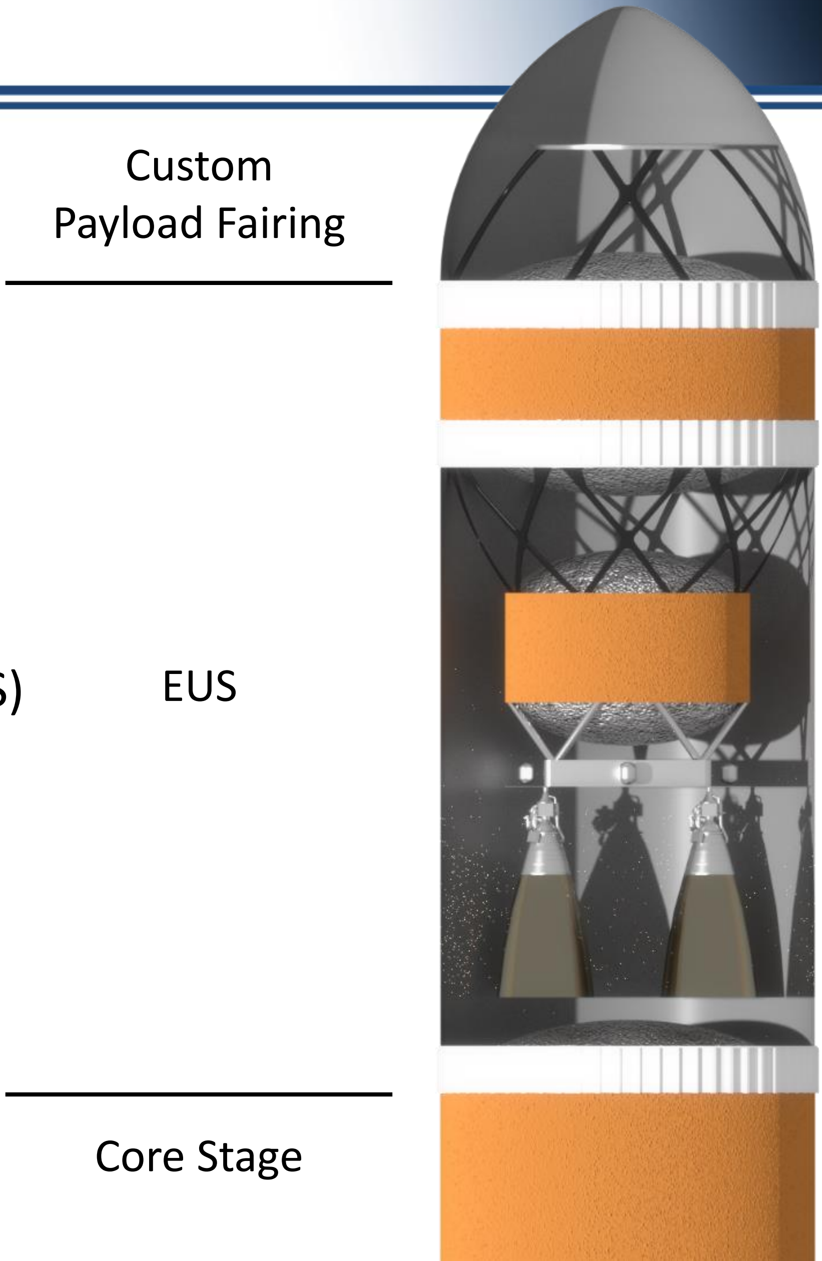


Launch II
SLS 1B

- Launch date: 21st November 2021
- Payload to LEO: 104800 kg (including EUS)

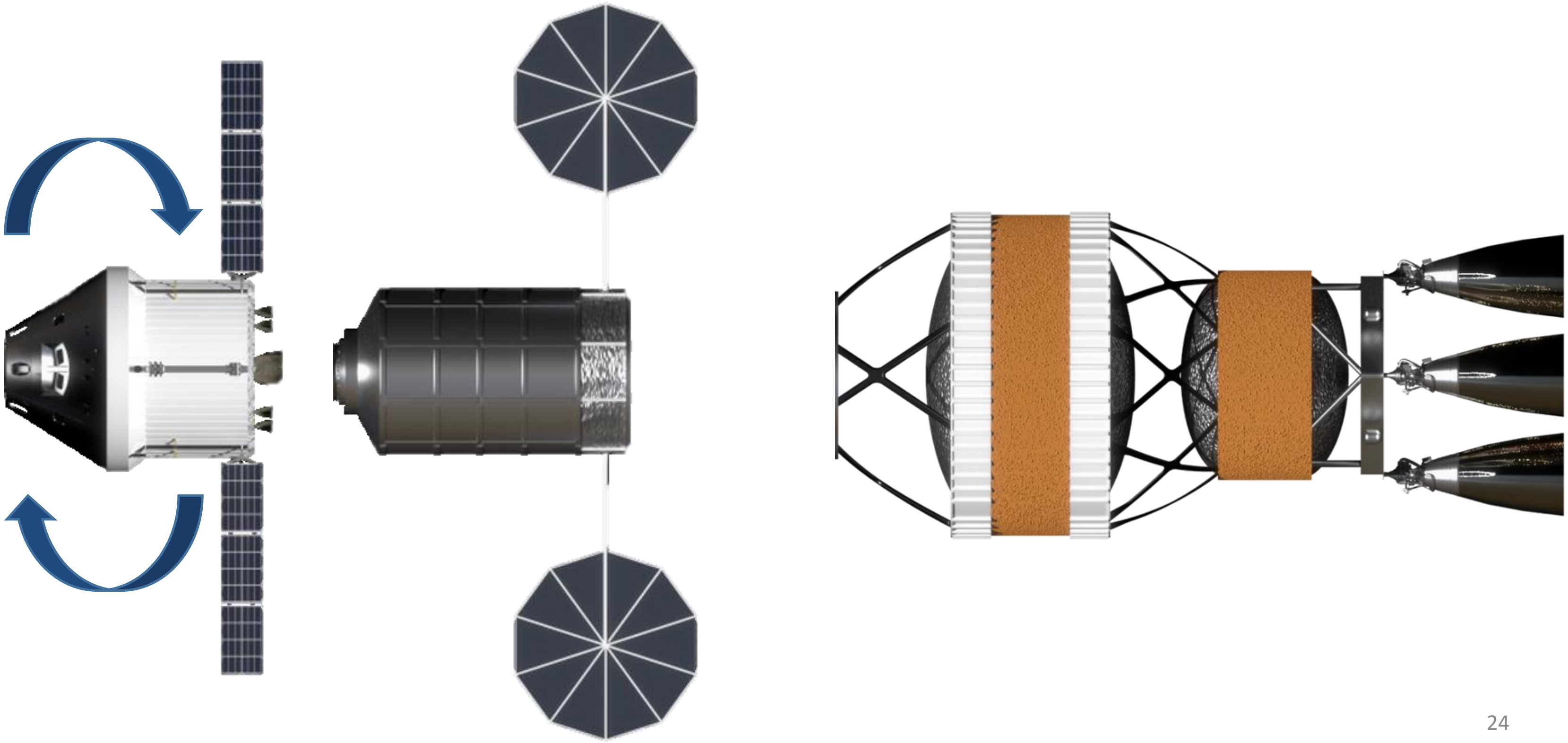
Rationale:

- Engine flight heritage (Centaur, STS)
- Reduced mission risk
- Reduced propellant boil-off



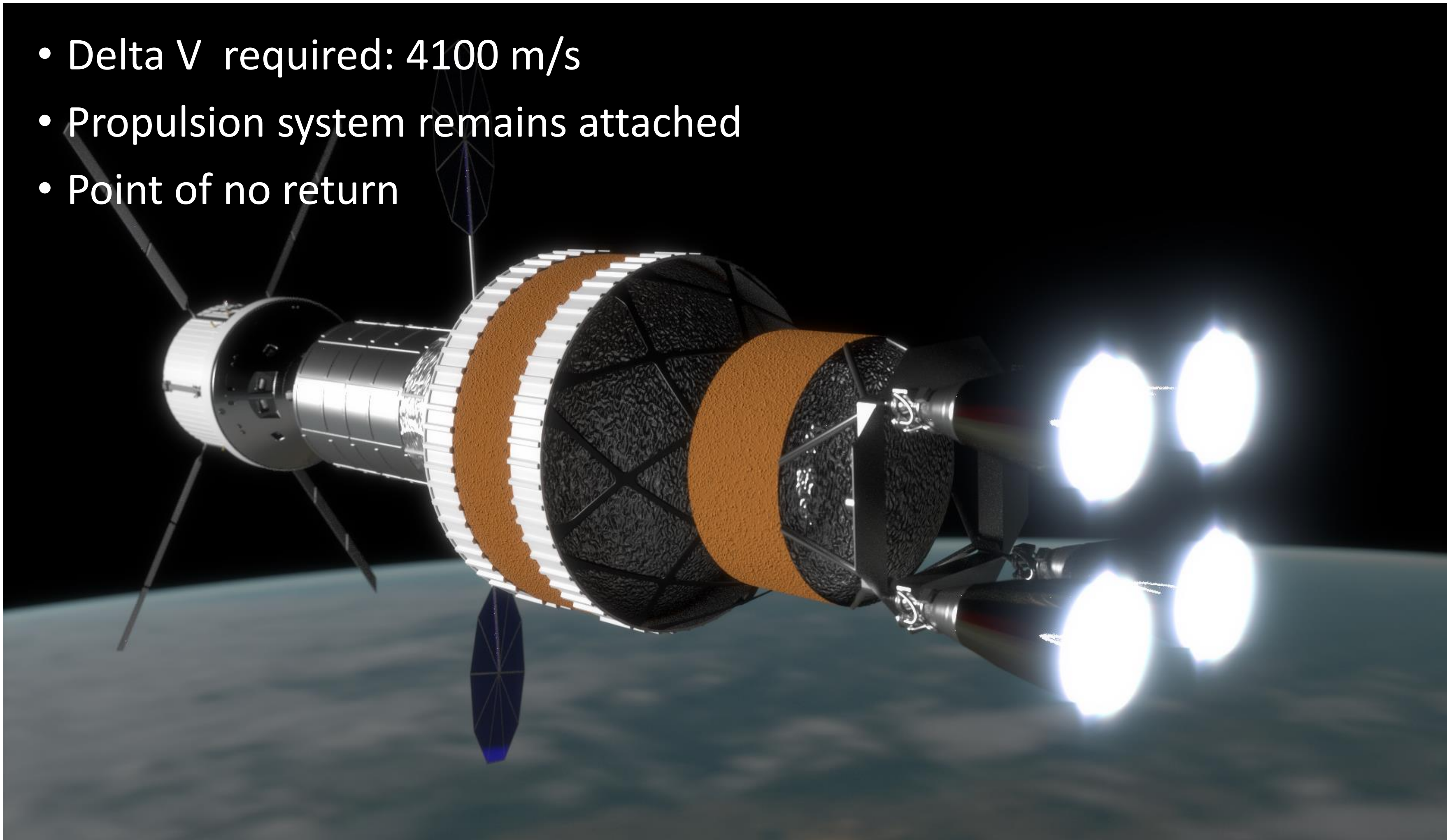
Earth Orbit

- Orion Capsule docks with MPLM habitat module
- One week grace period for testing and launch slip
- Propulsion system docks with habitat module



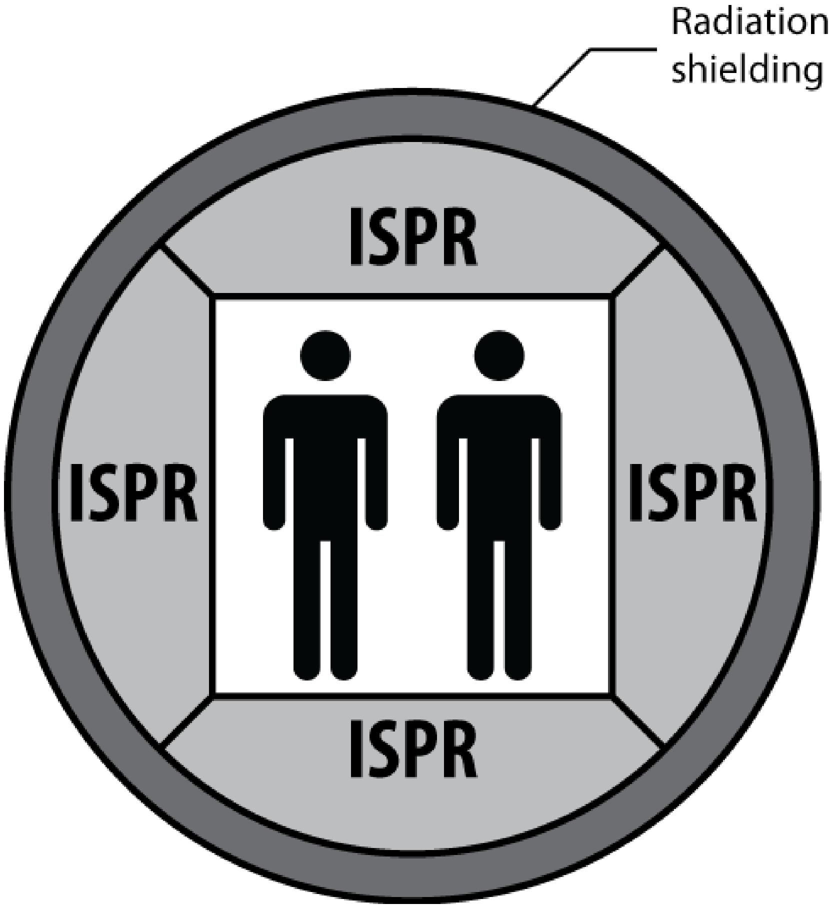
Trans Mars Injection – TMI

- Delta V required: 4100 m/s
- Propulsion system remains attached
- Point of no return



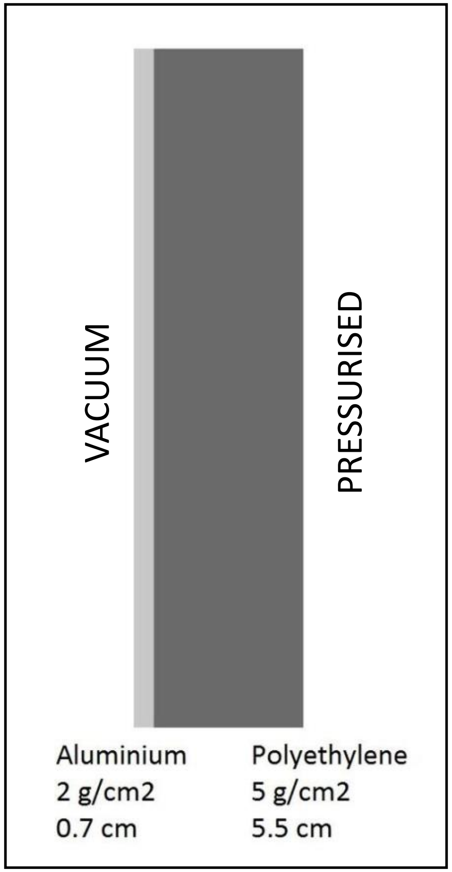
Internal Configuration

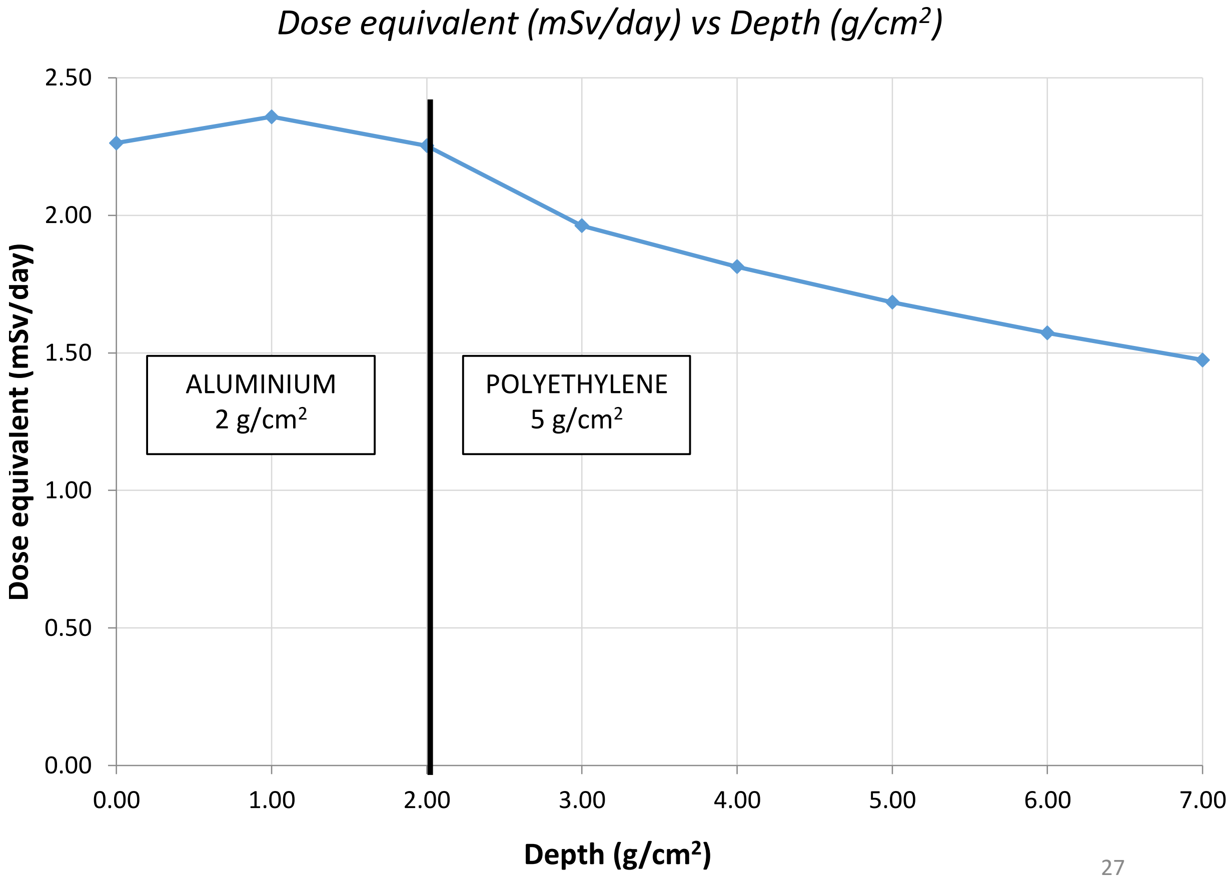
- Total Habitable Volume
  - Orion: 8.95m^3
  - MPLM: 24m^3
- Layout based on **Zvezda module**
- Use of ISS standard racks
- Service module offers additional non-pressurised volume
- Sleeping quarters double as **radiation vaults**



Radiation

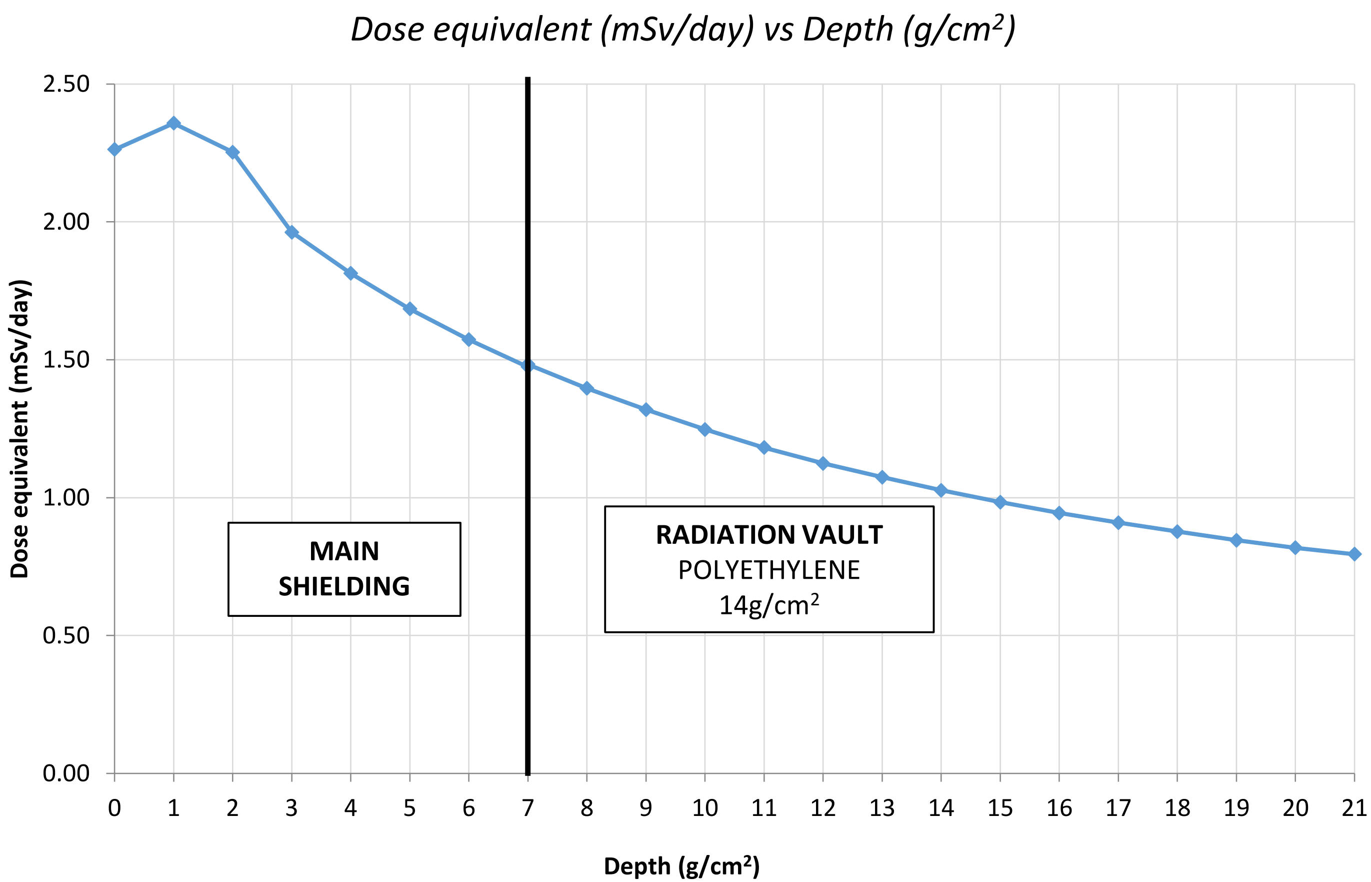
- Maximal dose of **730 mSv** during the entire mission (RQ04)
- **Polyethylene** has excellent properties for radiation shielding





Radiation

- Use of a **sleeping vault** to reduce the overall dose
- Radiation shielding total mass: 6900 kg



Venus Flyby

Closest approach altitude: 11000 km

Venus

Solar Flux
2601 W/m^2
0.723 AU

Earth

Solar Flux
1361 W/m^2
1 AU

Mars

Solar Flux
586 W/m^2
1.524 AU

Life Support
Atmosphere

Requirements

- O_2 consumption: 0.835 kg/CM-d
- Atmosphere filtration to a suitable concentration

Key characteristics:

- Pressurisation
- Leak rate
- Efficiency
- Reliability
- Reduced exposure to allergens

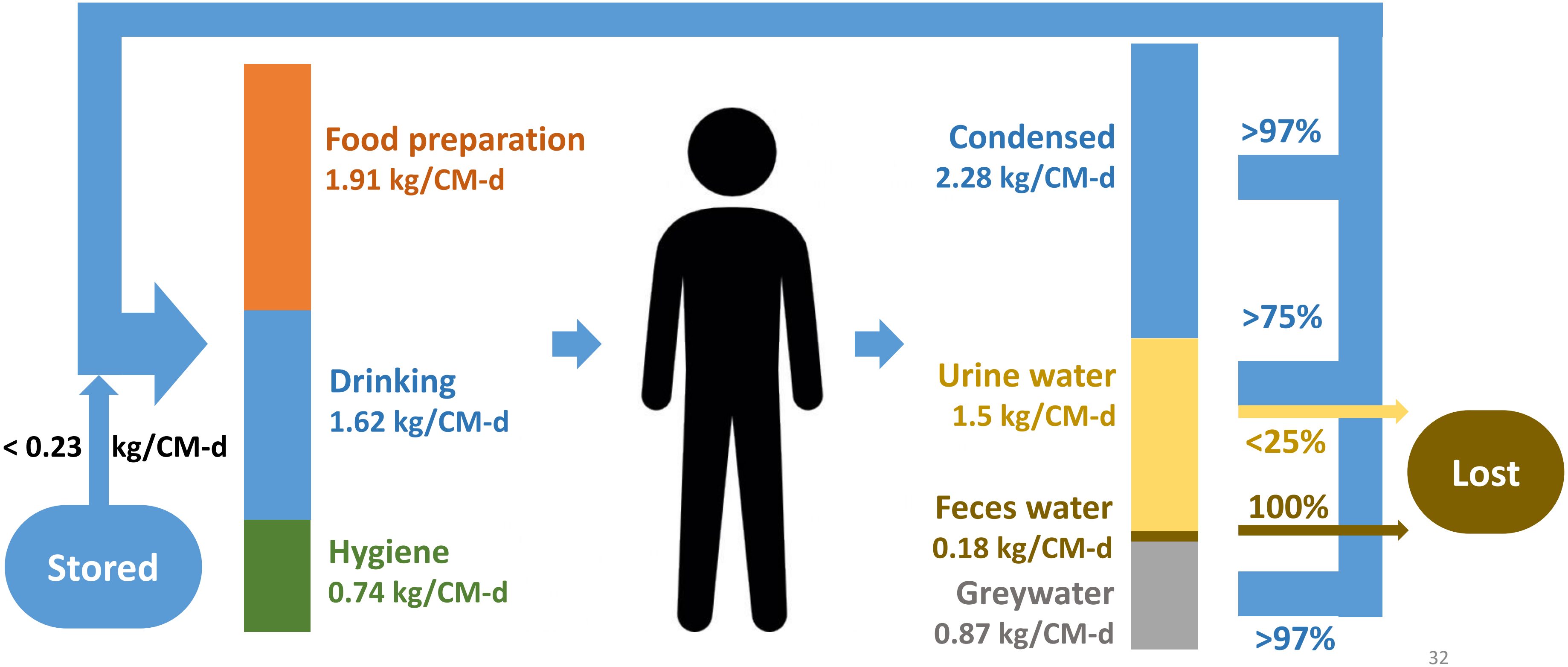
Solution:

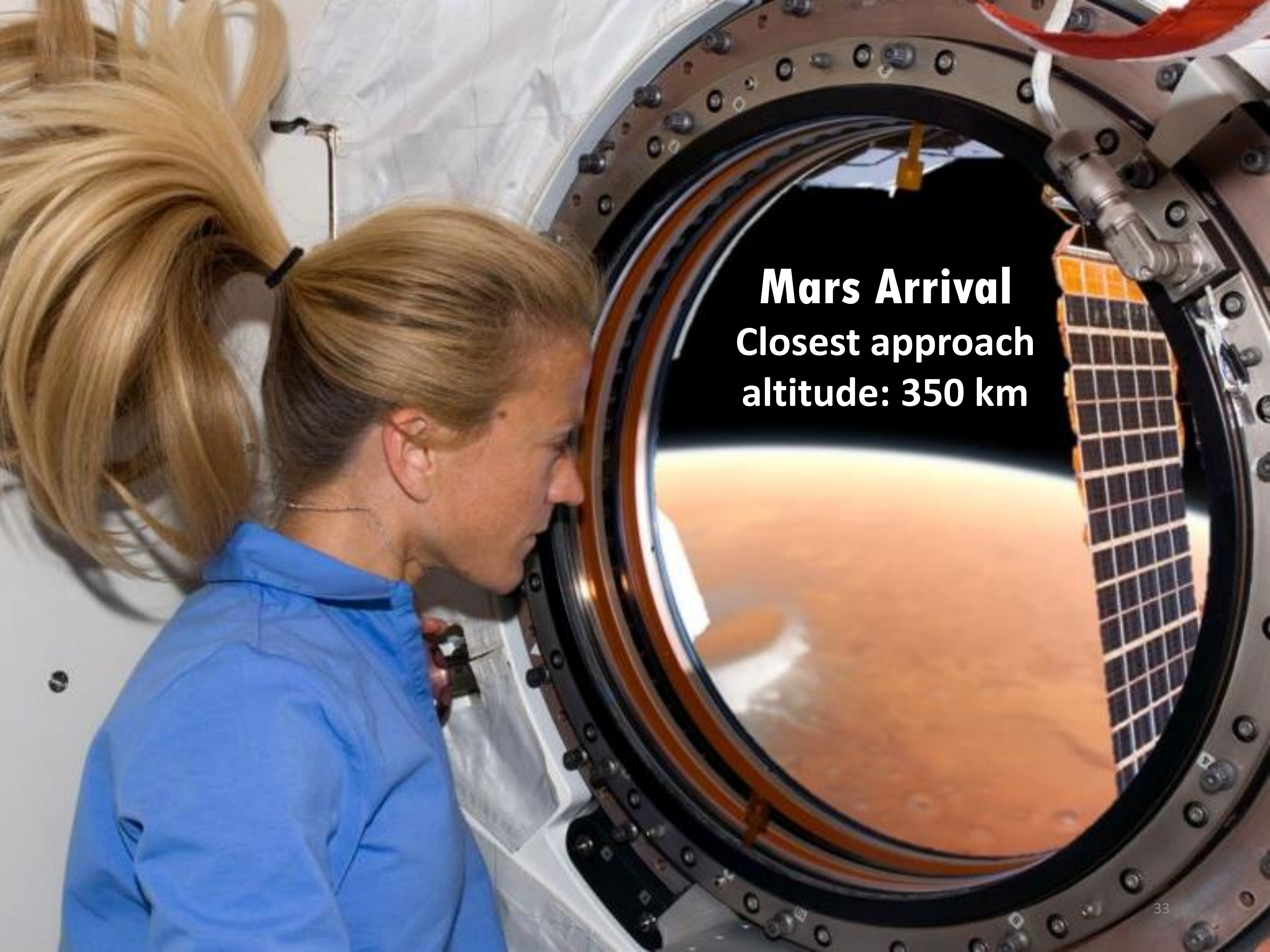
- **Sabatier** Process
- Improved ISS Oxygen Generation System (OGS)

TOTEM OGS	
Total N_2 required	**145.1 kg**
Water mass required for O_2	**500 kg**
Leak rate	0.06 kg/day
CO_2 scrubbing efficiency	75%
Sabatier efficiency	75%
Chamber pressure	101.3 kPa
Filter type:	Airocide

Life Support
Water and Food

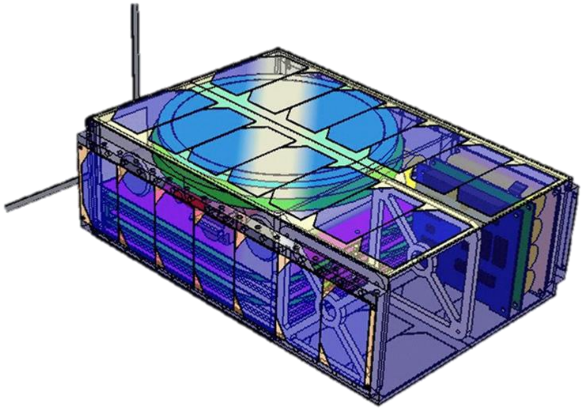
- Food mass: 755 kg (RQ01)
  - Reduced storage volume: **dehydrated food**
- Water recycling based on scaled-down ISS **Water Processor Assembly** (RQ05)
  - Closed loop not assumed



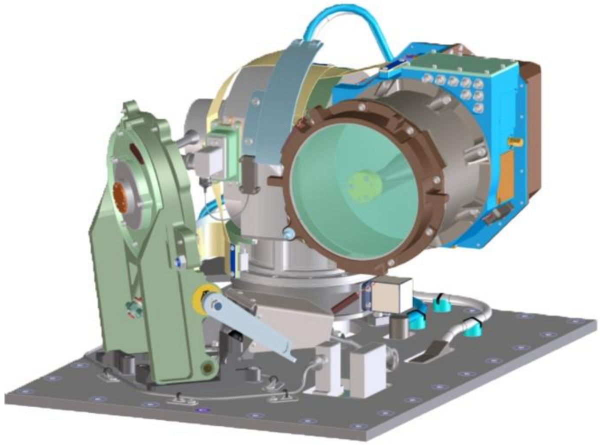

Mars Arrival
Closest approach
altitude: 350 km

Mission Science

- Technology Demonstration
  - High data rate **laser communication**
  - Biological **life support**
  - Microalgae **photo-bioreactor** for CO_2 removal and O_2 production
- Deep Space science
  - Recoverable interplanetary tests
  - Study of bacteria survival time
- Planetary Science
  - Surface penetrators
- Human science
  - Psychological & Physiological effects
  - Help mitigation for future missions



Self contained biological life support demonstrator



http://esc.gsfc.nasa.gov/assets/images/OpticalComm/OpticalModule.jpg

Human Health
Psychology and Physiology

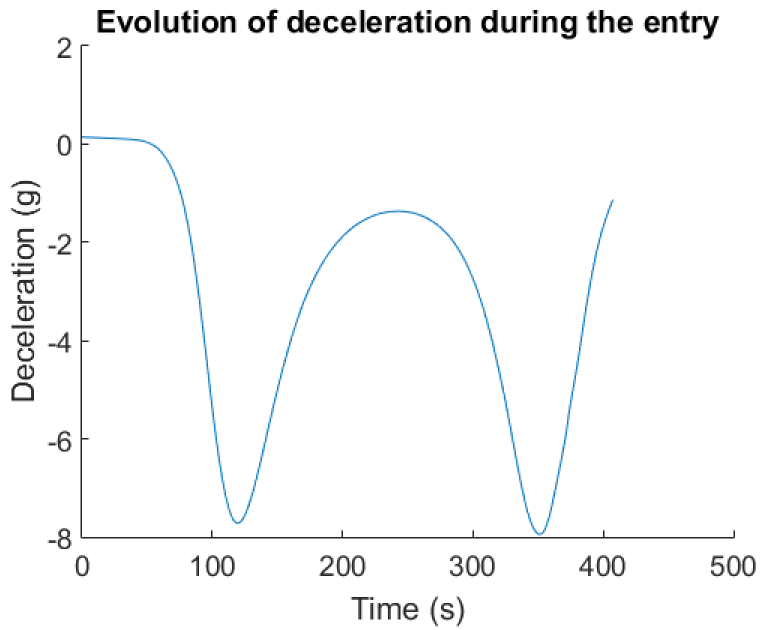
- A sound psychological environment is required:
  - Regular **communication** with Earth
  - Circadian lighting cycle – testing on ISS
  - Tending to plants (hydroponics etc.)
  - Compatibility with other astronaut
  - VR headsets

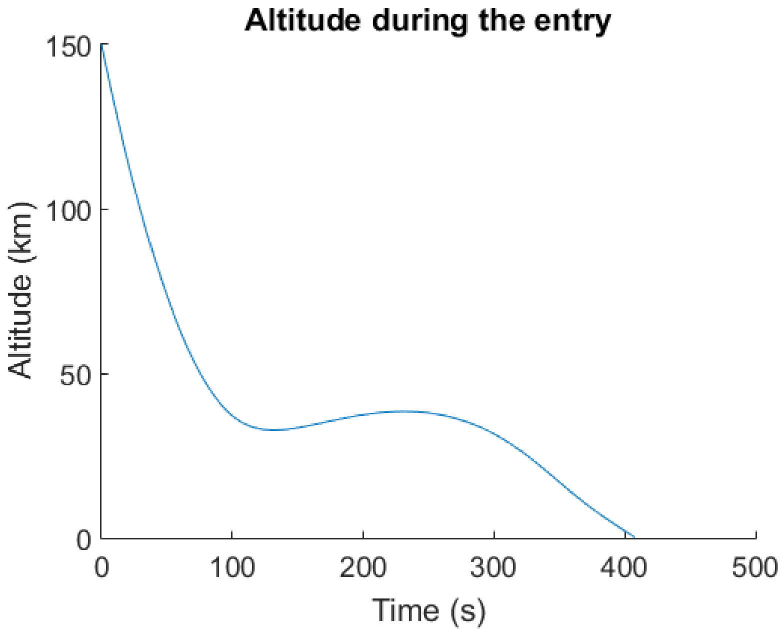
- Astronauts must maintain physically fit:
  - Treadmill
  - Rowing machine
  - Supplements
  - Motion sickness tablets
  - Pressure gradient suits
  - Trained to a high medical standard

http://blogs.ft.com/photo-diary/page/48/

Re-entry

- Orion undocks from MPLM (**one undock event**)
- Use of the Skip re-entry technique
- Re-entry time: 7 minutes
- Peak acceleration: 8g
- Cumulative acceleration over 5g: 100s



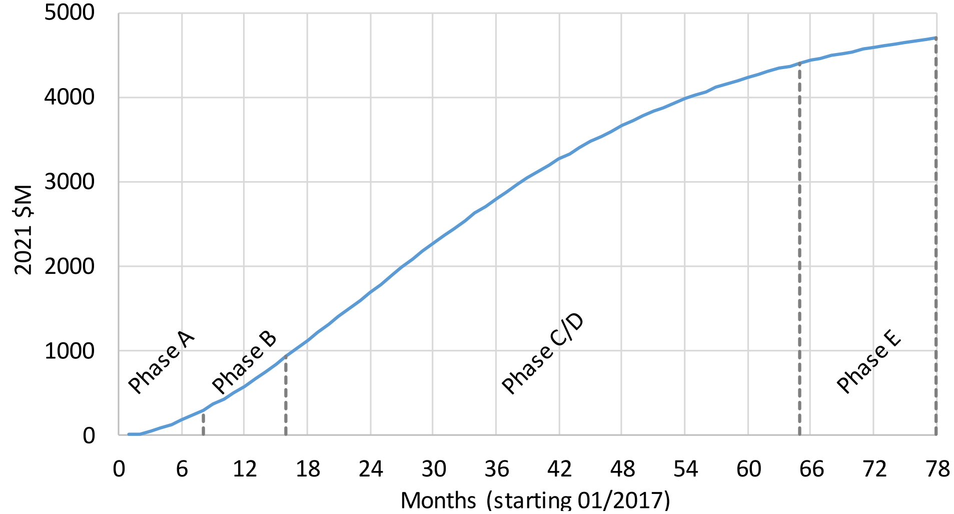


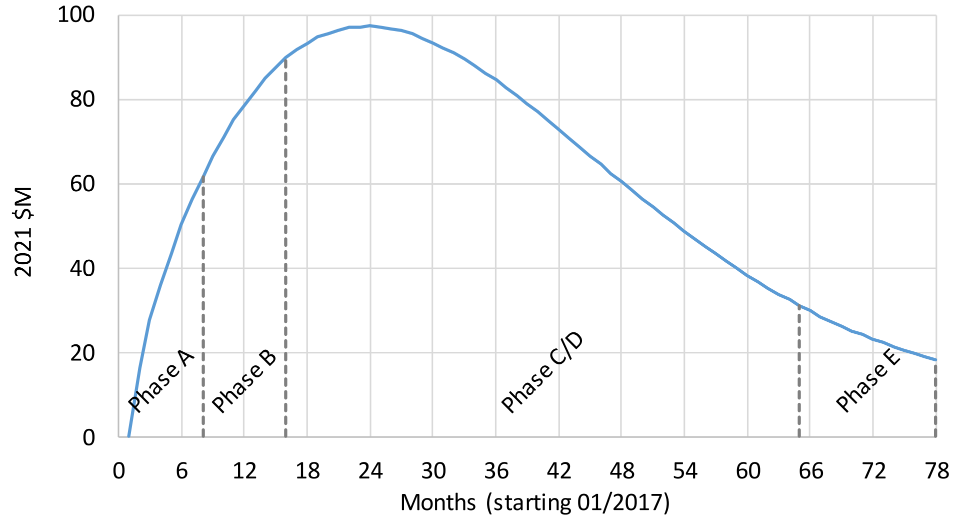
http://images.spaceref.com/news/2010/oo20100506_reentry.jpg

Costs

Cumulative Costs

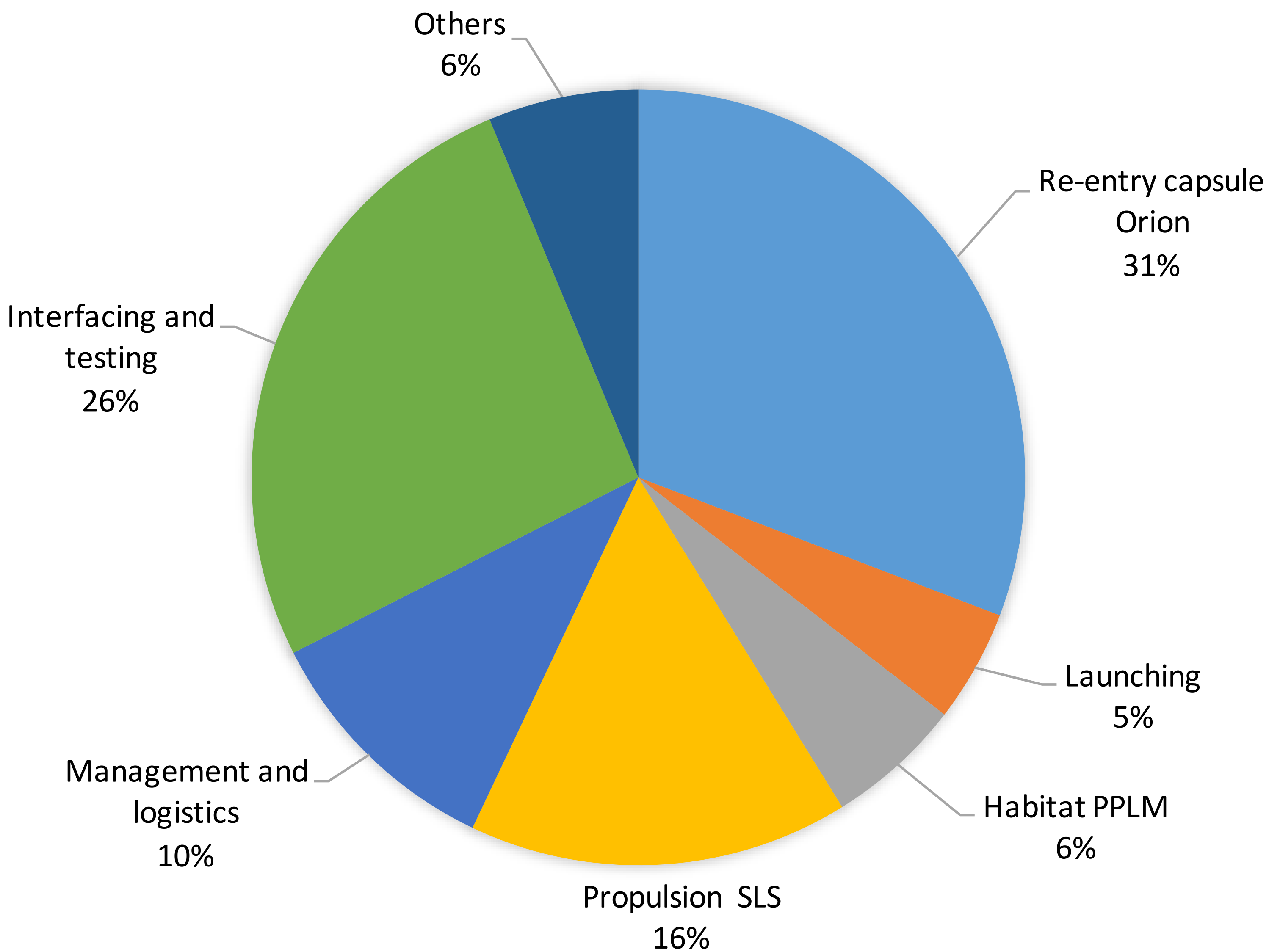
- Total cost: 4.7 billion USD
  - FY2021
- Apollo: 156 billion USD
  - 10 manned missions
  - FY2021
- 78 months investment
- Comparison
  - Advanced Mission Cost Model
  - CER's cost regression
  - < 10% difference





Costs

Total: 4.7 Billion USD



Summary

- Heritage in design components
  - Orion, MPLM, Exploration Upper Stage
- Two launches
- Mission duration: 580 days
- EVME trajectory
- Payload for Mars flyby: 41560 kg
- Habitable volume: 33 m^3
- Mission Cost: $4.7 Billion USD FY2021

Questions?

Visit mars.cranseds.co.uk for more

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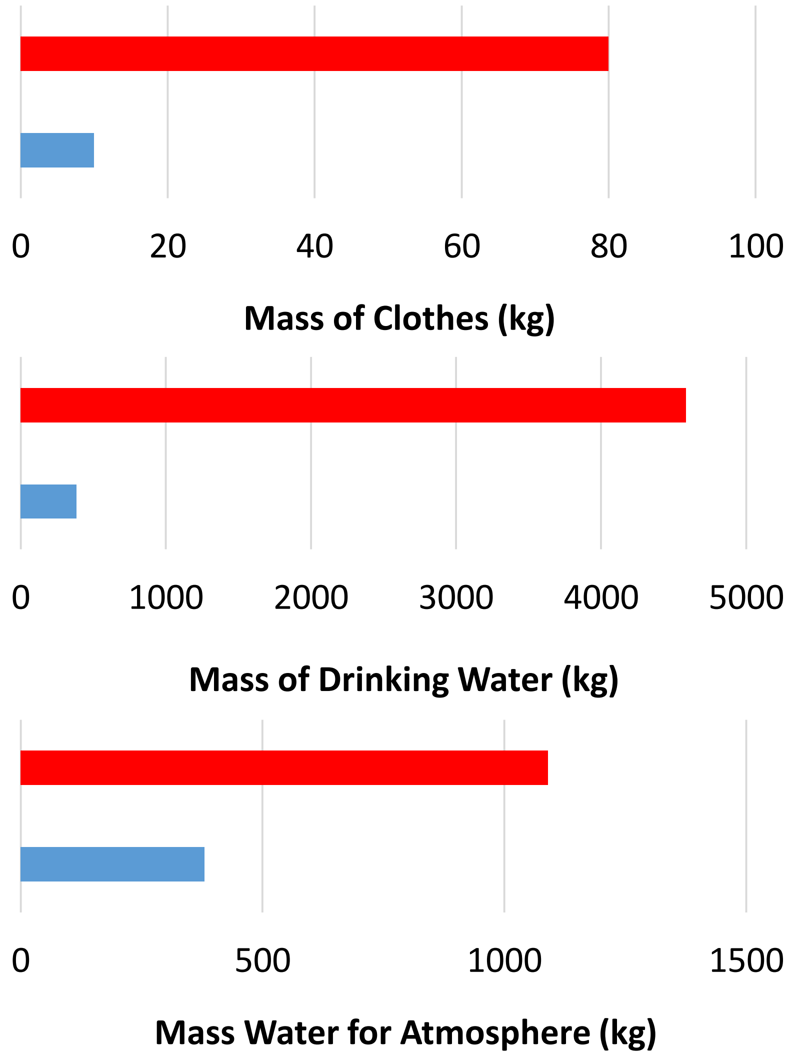
Cranfield University

Backup Slide – Life Support

On-board Recycling

- Recycling is a key factor in mission success
- Overall mass saving: > 5000 kg
- Heat melt compactor reduces waste volume



Non-recycling

Recycling

Backup Slide – Launch
SLS 1B

- Delta V to orbit estimated from conservative maximum LEO payload (97.1 tonnes – Pietrobon 2015)
  - This would have underfilled EUS
- Fairing separation assumed at core stage burnout (conservative)
- Assume equal total Delta V for 1 tonne payload → 89.3 tonnes useable propellant remains in EUS

Flight phase	Delta V (97.1 tonnes LEO)	Delta V (1 tonne LEO)
Core + boosters	2429 m/s	2452 m/s
Core only	5575 m/s	5774 m/s
EUS	1557 m/s	1335 m/s
Total	9561 m/s	9561 m/s

Element	Mass at ignition (tonnes)	Inert mass (tonnes)	Specific impulse (s)
Booster (each)	729.2	100.9	265.4
Core stage	1074.7	110.3	452.2
EUS	139.7 (full prop load)	14.5	462.0

Backup Slide – Power

Power Breakdown

- ISS ECLSS subsystems typically have duty cycles <50%
- Two standard operating modes: subsystems “take turns” in standby mode

<table>
<tr><th>Subsystem</th><th>Power/W (mode 1)</th><th>Power/W (mode 2)</th></tr>
<tr><td>WPA</td><td>404</td><td>164</td></tr>
<tr><td>OGA</td><td>1210</td><td>132</td></tr>
<tr><td>CDRA</td><td>132</td><td>1210</td></tr>
<tr><td>HMC</td><td>0</td><td>600</td></tr>
<tr><td>Air purifier</td><td colspan="2">66</td></tr>
<tr><td>Algae bioreactor</td><td colspan="2">93</td></tr>
<tr><td>Coolant loop pumps</td><td colspan="2">330</td></tr>
<tr><td>Avionics</td><td colspan="2">110</td></tr>
<tr><td>Other Electronics</td><td colspan="2">275</td></tr>
<tr><td>Other fluid pumps</td><td colspan="2">360</td></tr>
<tr><td>Communications</td><td colspan="2">183</td></tr>
<tr><td>Science</td><td colspan="2">1100</td></tr>
<tr><td>AOCS</td><td colspan="2">110</td></tr>
<tr><td>System-level margin (20%)</td><td>875</td><td>947</td></tr>
<tr><td>Total</td><td>5248</td><td>5680</td></tr>
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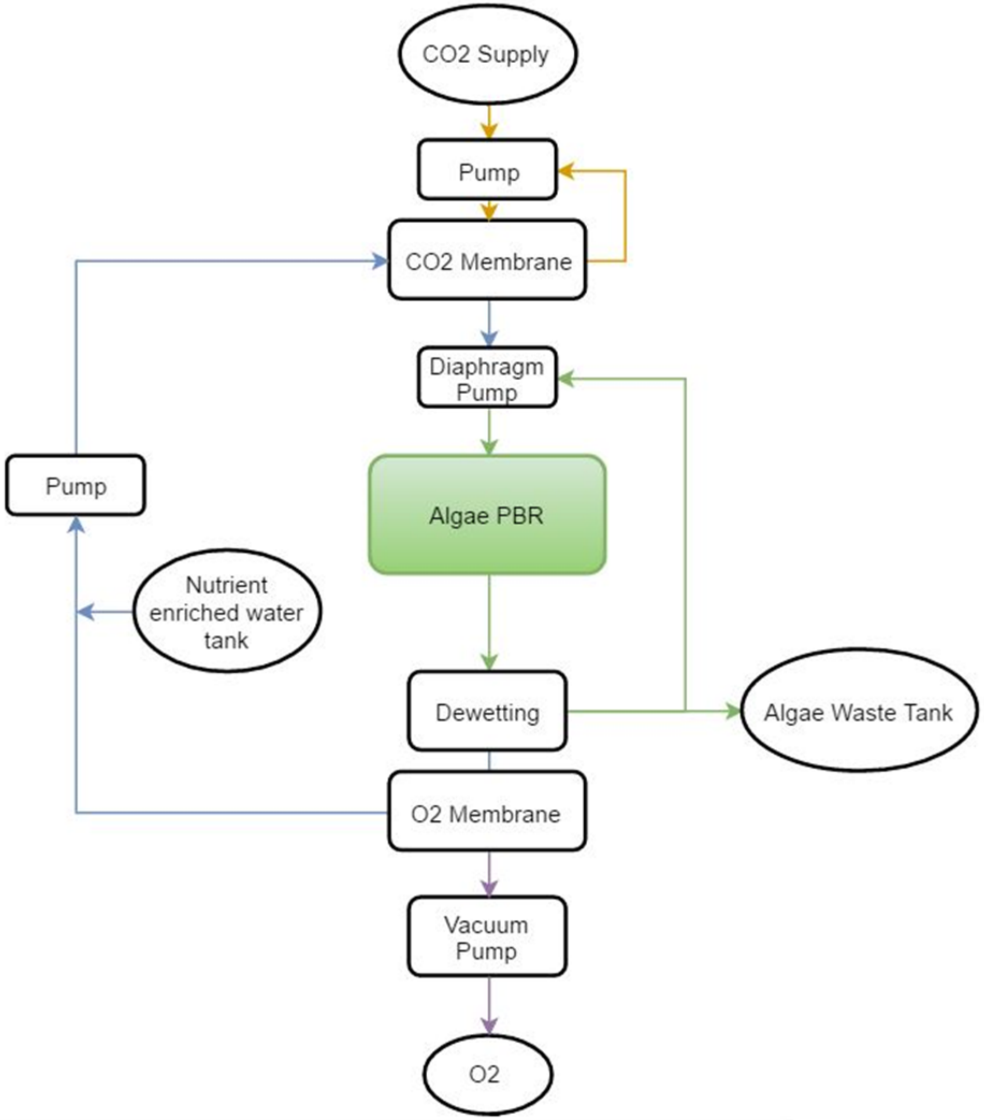
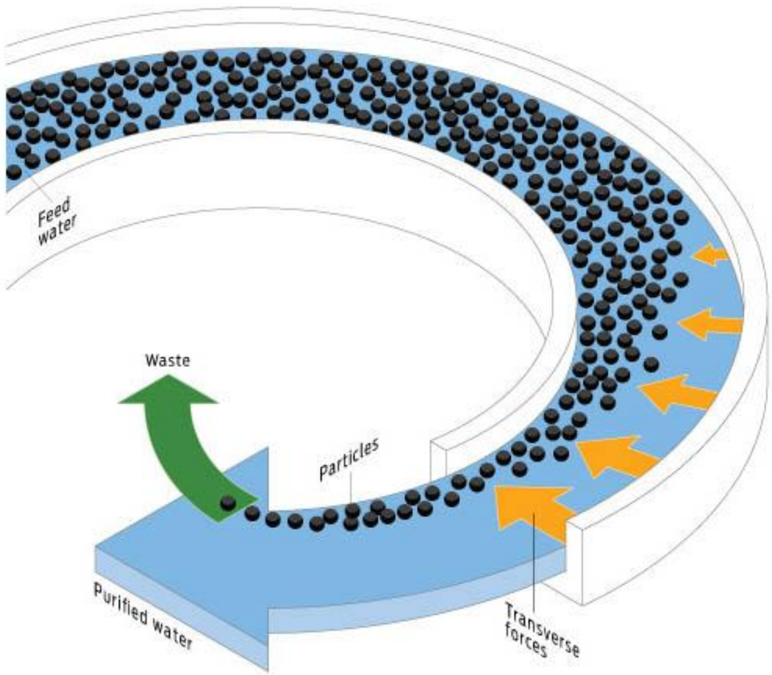
Backup Slide – Atmosphere

Leak rate calculations

	Nitrogen	Oxygen
%pressure	0.78	0.21
Total pressure	101.3	kPa
Spec gas const	287.058	J/(K-kg)
Temp	293	K
density	1.204404	kg/m^3
density of O2	0.252925	kg/m^3
density of N2	0.939435	kg/m^3
volume	100	m^3
mass of O2	25.29248	kg
mass of N2	93.94351	kg
~total air mass	119.236	kg
leak/day	0.059618	kg/d
Total leak	**34.57844**	**kg**
Total N2 req	**120.9147**	**kg**
Leak O2 req	7.261472	kg
Leak N2	27.31697	kg

Biological Life Support
Thin layer decoupled PBR





Backup Slide – Cost

Cost Breakdown

Phase	Description	Total in FY21	Percentage
A-D	Development Support Facility	$17M	1%
A-D	Project Management	$170M	5%
B	Project Systems Engineering	$255M	8%
B	Safety and Mission Assurance	$119M	4%
B-D	Configuration Management	$68M	2%
C/D	Orion Module	$1000M	31%
C/D	SLS	$516M	16%
C/D	PPLM	$185M	6%
C/D	Contractor and subcontractor Fee	$170M	5%
C/D	Hardware/Software Integration	$221M	7%
C/D	Integrated Logistics	$102M	3%
C/D	Systems, integration and test	$204M	6%
E	Product Assurance	$51M	2%
E	Site Activation	$17M	1%
E	Launch Vehicles & Services	$135M	4%
E	Annual Operations and Support for Ground Station	$16M	1%
Total		$3248M	100%
	Reserves	$1462M	45%
Total		$4709M	

Backup Slide – Food

Food Mass calculations

Assumptions:

- Average Metabolic Rate of **2,677 calories** per day
- Respiration quotient of **0.87**

Results in dried food mass of **0.62kg/CM-d**

Mission duration: **580 days**

Crew size: **2**

Food required: **720kg**

With **5%** margin: **755kg**

Backup Slide – Communication

Link Budget Analysis

Transmitter				**Reciever**			
Antenna Diameter		3	m	Antenna Diameter		35	m
	Gain	1010647.5			Gain	137560352.9	
		60.045997	dB			81.38493281	dB
Power	56.16403093	W		Power	1.00E-14	W	
Power Transmitted		17.49	dBW	56.16403093	W		
Power Received		-140.00	dBW				
Gain Reciever		81.384933	dB				
Gain Transmitter		60.045997	dB				
FSL		-294.5736	dB				
Reciever Losses		-3	dB				
Transmitter Losses		-2	dB				
Margin		3.7	dB				
System Noise Temp		19.0309	dB				
Data Rate		63.222193	dB				
Eb/No		2	dB				
Boltzman		-228.6012	dB				

Frequency	32	GHz
Wavelength	0.009375	m

Distance	2.67	AU
	3.99432E+11	m

System Noise Temp	80	K
Data Rate	2100	kbps

Backup Slide – High Level Risks

	Risk	Consequence	Likelihood	Severity		Mitigation
Devel.	Crew vehicle readiness/delivery on time	Unable to launch	1	5	5	Delivery plan with systems providers
	Habitat module readiness/delivery on time	Unable to launch	1	5	5	Delivery plan with systems providers
	Launch vehicle readiness/delivery on time	Unable to launch	1	5	5	Delivery plan with systems providers
Launch	Systems launch delay	Postponed operations	2	2	4	Operations in advanced for launch window
	Systems launch failure	Loss of major systems	1	5	5	Use of qualified or flight proved design
	Crew launch delay	Postponed operations	2	2	4	Operations in advanced for launch window
	Crew launch failure	Loss of the crew	1	5	5	Use of qualified or flight proved design Flight abort system
Operation	Crew and systems dock failure	Unable to transit	1	4	4	Crew training and interfaces tests
	Trajectory failure	Unable to transit	1	4	4	General system check prior burn
	Solar radiation peaks	Threat to crew and systems	1	3	3	Shielding modification for the habitat Crew emergency procedures and individual radiation shielded cubicles Mission schedule considering solar cycles
	Habitat failure	Threat to crew and systems	1	4	4	Use of flight proved design Mechanical/electrical ground tests of interfaces Orion used as "lifeboat"
	Habitat modification failure	Crew contamination	2	4	8	Use of qualified or flight proved design Mechanical/electrical ground tests of interfaces
	Interface capsule/habitat failure	Loss of crew	1	5	5	Use of qualified or flight proved design Mechanical/electrical ground tests of interfaces
	Interface habitat/upper stage failure	Loss of the propulsion Loss of the crew	1	5	5	Use of qualified or flight proved design Mechanical/electrical ground tests of interfaces
	Communication system failure	Loss of direct communication	2	3	6	Communication periods apart from operational critical events Use of alternative/redundant system
	Power system failure	Systems partially or totally dead	1	4	4	Ground tests of batteries and solar panels Orion/habitat redundancy
	Life support system failure	Threat to crew	1	4	4	Use of qualified or flight proved design Orion/habitat redundancy Algae bioreactor
Crew	Waste management failure	Limited crew operations	2	3	6	Use of qualified or flight proved design Ground cycle tests
	Crew illness	Unable to perform mission activities	3	3	9	Crew training and monitoring Medical supplies
	Crew "backwards acceleration"	Physical injuries to the crew	2	2	4	Acceleration profile Crew monitoring
	Internal repairs/tools	Unable to perform mission activities	3	1	3	3D printer, filament and digital repository of printable items