



# **Scenario E Status:**

## **A Flexible Path of Human and Robotic Exploration**

Presented to the  
Review of U.S. Human Space Flight Plans Committee  
7/22/2009  
Denver, Colorado

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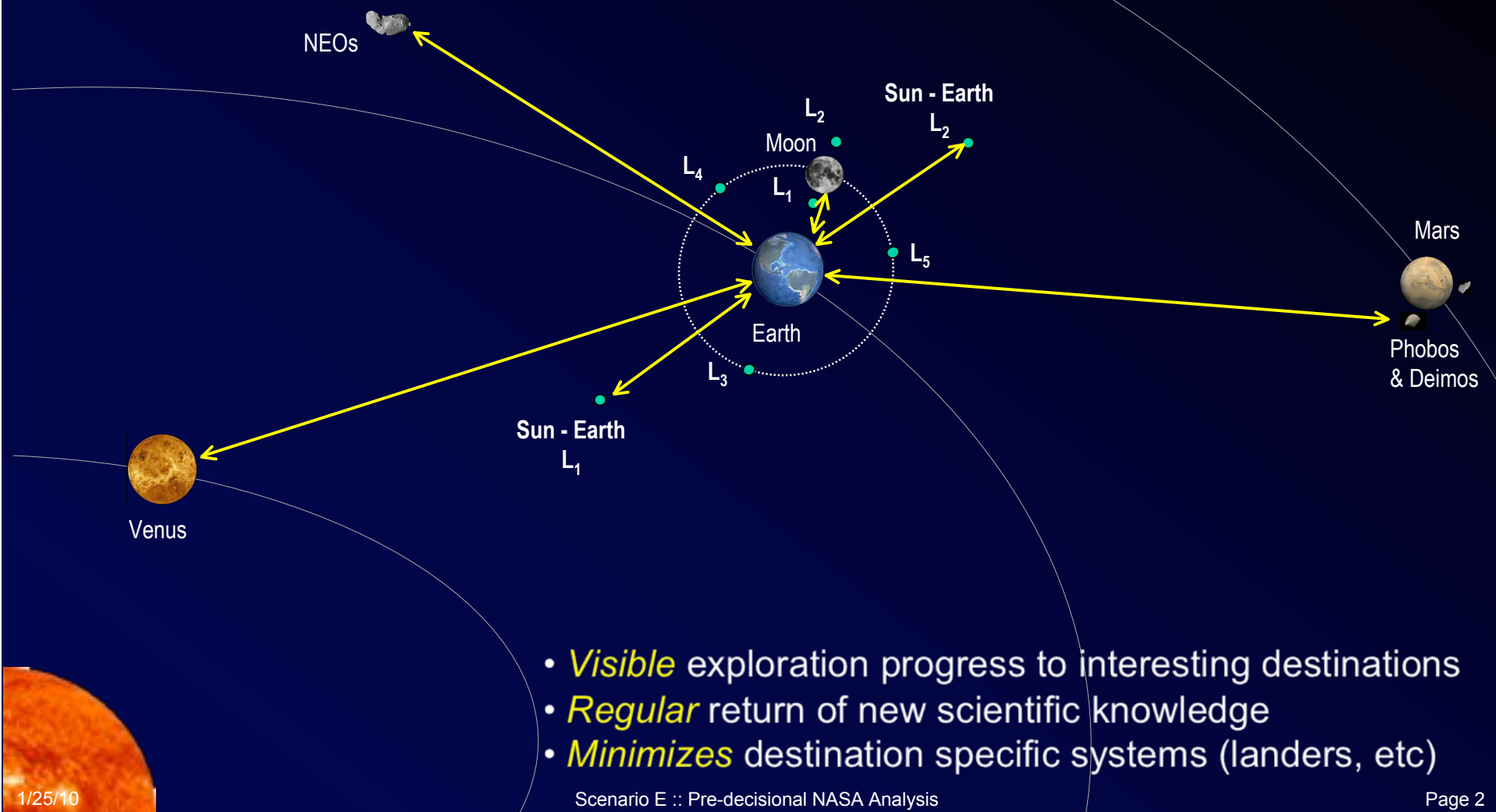
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# Scenario E) Flexible Path



- Piloted missions to *many* places in the inner solar system
- *Orbit* planets with deep gravity wells; *Rendezvous* with small bodies
- *Tele-robotically* explore and sample planetary surfaces

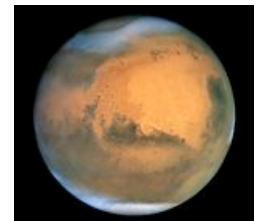
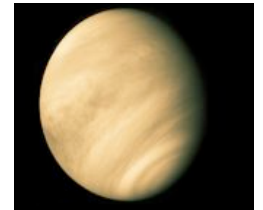


# ***A Flexible Path of Human and Robotic Exploration***



## ◆ **A Flexible Path for Exploration**

- Frequent, measured, and visible human exploration of space beyond Earth orbit
- Cross-leverage the human and robotics capabilities
- Gain operational experience and system validation
  - For long duration missions (90 – 600 days) beyond low-Earth orbit (LEO)
  - In vicinity of low-gravity planetary bodies



## ◆ **Key Scientific Return**

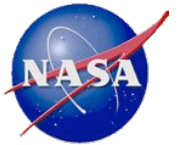
- Exploration while producing exciting new science each step of the way
- Understanding human impacts of
  - long-term radiation environment in deep space
  - extended exposure to micro-gravity environment
- Multi-kilogram sample return from solar system bodies. Some radically different from Moon/Mars
- Telerobotic exploration and sampling of the surface of Mars



Itokawa.  
Courtesy JAXA

## ◆ **Public Engagement and Inspiration**

- Cultivate and maintain public support by taking on demonstrably new, visible and different space missions
- Unprecedented deep space missions with dramatic perspective of the Earth-Moon system and voyages to NEOs, Mars and Venus



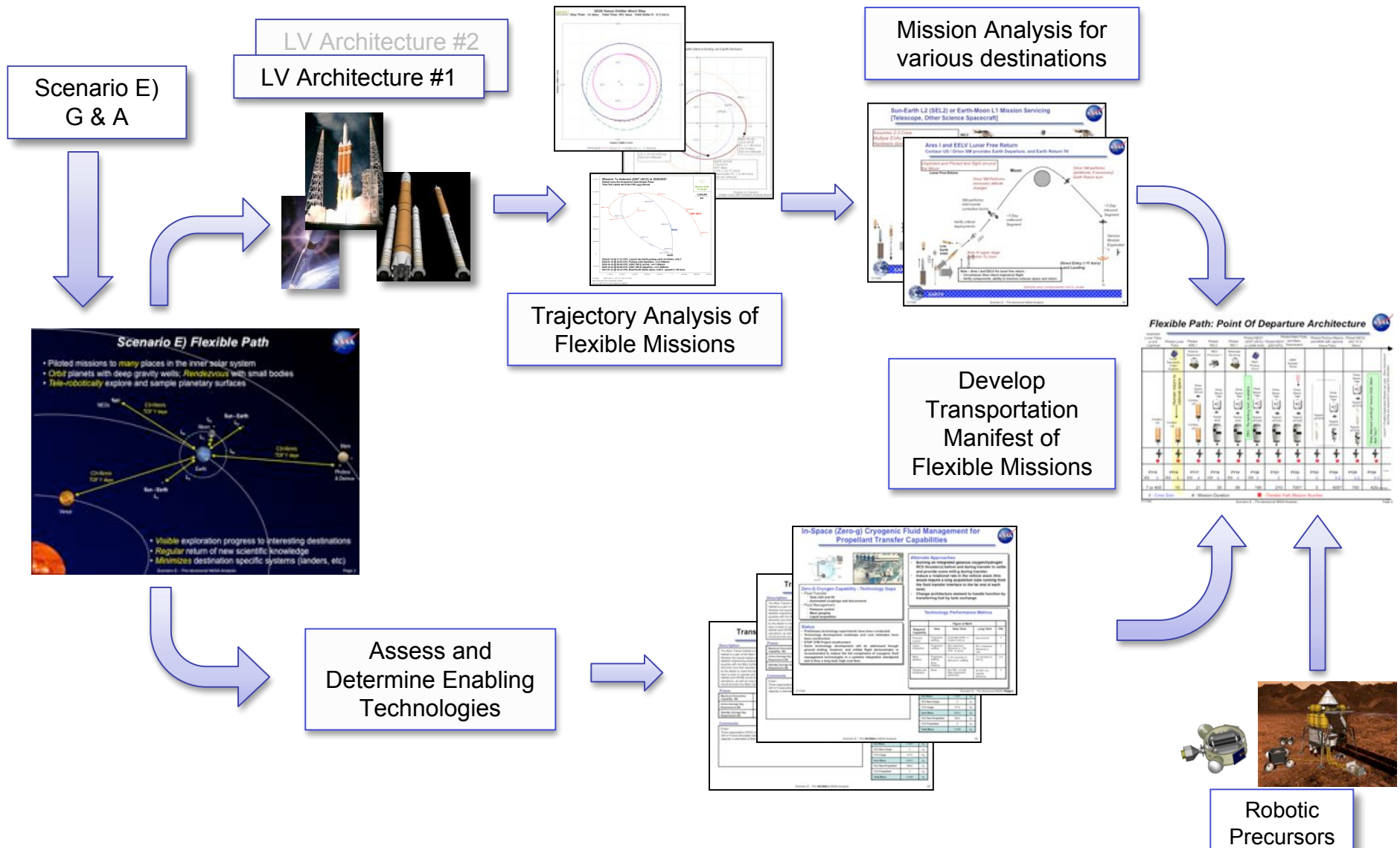
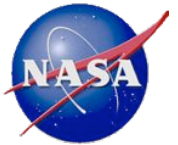
## Ground Rules

- Piloted missions to many different venues is a key metric
- Planetary surfaces within a deep gravity well will be accessed telerobotically by the Crew
- Robotic precursors to NEO missions, and for Mars surface sample collection
- TransHab or equivalent habitat space is commercially / IP available
- Using Constellation launch vehicle capabilities as baseline; Ares I & V
- Orion capsule used for crew launch from Earth, Earth entry, descent and landing (EDL), and in-space piloted missions. No changes other than block upgrades

## Assumptions

- 1 crewed flight, plus 1-2 cargo missions, per year
- 3-5 person crew with closed-loop Environmental Control & Life Support System (ECLSS) mass which varies with mission duration
- EELV upper stage with low boil-off available in 2015
- Cryogenic oxygen/hydrogen Earth Departure Stage (EDS) with low boil-off available initially and on-orbit "Topping-off" of EDS in LEO available (not necessarily a depot)
- Nuclear Thermal Rocket (NTR) propulsion available in late 2020's
- Mission maximum duration of approximately 2 years
- Earth entry velocity not to exceed 12 km/s
- Chemical Isp = 448 sec; NTR Isp = ~900 sec

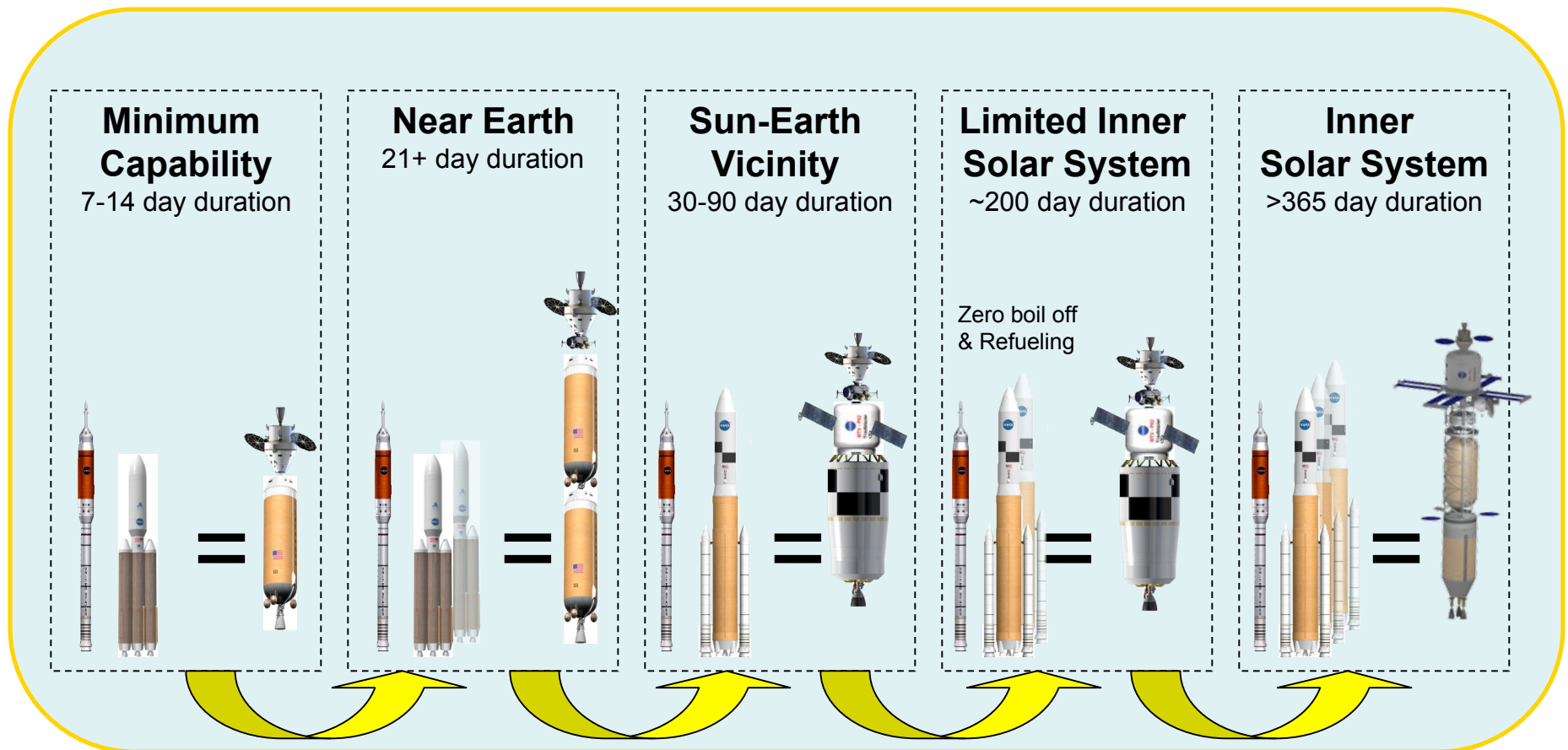
# Scenario E Analysis Process



# Flexible Path: Evolving Sequence of Missions










































- ◆ The Flexible Path Scenario is a sequence of missions with increasing capability into the inner solar system



# Flexible Path: Point Of Departure Architecture



Unpiloted Lunar Flyby or S-E Lagrange	Piloted Lunar Flyby	Piloted EML1	Piloted SEL2	Piloted SEL1	Piloted NEO1 (2007 UN12) /(2008 EA9)	Piloted NEO2 (2001GP2)	Piloted Mars Flyby and Mars Telerobotics	Piloted Phobos Mission and MSR Capture	Piloted NEO3 (AO 10 or Other)			
NEO Precursor 1 	 Lunar Telerobotic Crater Explorer	Science Deployment? 	 Mars Phobos Scout	Telescope Servicing 		NEO Precursor 2 	 MSR Sampler Rover	 MSR Sample Capture at Phobos				
 Centaur US	Human return to cislunar space ↓  Centaur US	Deep Space Airlock  Centaur US  Centaur US	Deep Space Hab  Partial EDS 	Deep Space Hab  Partial EDS 	ZBO / Re-tanking tech. available	Deep Space Hab  Topped off EDS 	Deep Space Hab  Topped off EDS 	IOC ↓ Deep Space Hab  Topped off EDS 	Deep Space Hab   Centaur US 	Deep Space Hab   Centaur US 	Mars Manned Landing? Venus Orbit, Main Belt Tour?	
 1	 2	 3	 4	 5		 6	 7	 8	 9	 10	 11	
FY15 ISS 0	FY16 ISS 4	FY17 ISS 4	FY18 ISS 4	FY19 ISS 4	FY20 ISS 3	FY21 5	FY22 5	FY23 0	FY24 3	FY25 3-5	FY26 3-5	...
7 or 400	10	21	30	90	190	210	700?	0	~760	150	420(Venus)	
# - Crew Size		# - Mission Duration			# - Flexible Path Mission Number							

# Key Scenario E Trades & Sensitivities

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## • Transportation Options

- Two Ares I (one crew, one cargo)
- EELV Options
  - Current EELV upper stage
  - Evolve to Enhanced EELV
- Timing of Ares V
- **Human-rated Ares V or Ares IV**
- Orion Service Module Delta-V modifications
- In-space engine (J-2X, RL-10, NTR, etc.)
  - Long duration functionality
  - LOX/H<sub>2</sub> Performance (Isp 448 – 470 sec)
  - Safety and reliability
  - **Chemical vs NTR**

## • **On-orbit Propellant Transfer**

- “Top-off” propulsive stages vs. depot(s)
- Active vs. passive boil-off mitigation
- **Staged partial full EDS vs top-off full EDS**

## • Habitation / Life Support / Human Factors

- Crew (3-5) Habitat size
- ECLSS Closure
- Logistics staging prior to TEI
- Sustainable food growth
- Induced Gravity
- Radiation protection method

## • Cost

- Flight Rate
- ISS commercial handover date
- Phase Progression timing

## • Mission Planning

- Delta-V vs flight duration
- Short-stay vs. long-stay
- Time between launches
- Locale at destinations
  - Flyby
  - Halo orbit
  - Vicinity / highly elliptical orbit
  - Low circular orbit

# ***Launch Vehicle LEO Payload Classes & Usage***

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## **◆ 25 t Class (for Orion or Centaur upper stage)**

- Ares I (or other Shuttle heritage vehicle) for Orion launch
- Existing/Upgraded EELV (Delta IV-H, Atlas V-H) for Centaur upper stage
- Falcon 9 Heavy?

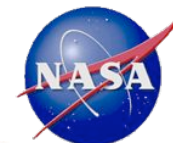
## **◆ 70 t Class (for EDS, Hab, NTR, and/or Orion)**

- Ares V or IV
- Shuttle Derived (side-mount and in-line payload options)
- Evolved EELV

## **◆ 100 – 120 t Class (for EDS, Hab, NTR, and/or Orion)**

- Shuttle Derived (in-line payload option with upper stage)
- New Design (Shuttle and/or EELV heritage, up to ET dia. Core)

# *In-space Propulsion and Propellant Resupply Trades*



With propellant resupply, an EDS could perform transfer mission injection for Flexible Path missions

- ◆ Trade EDS use/resupply vs NTR development costs/use
- ◆ Trade EDS staging vs EDS propellant resupply for missions



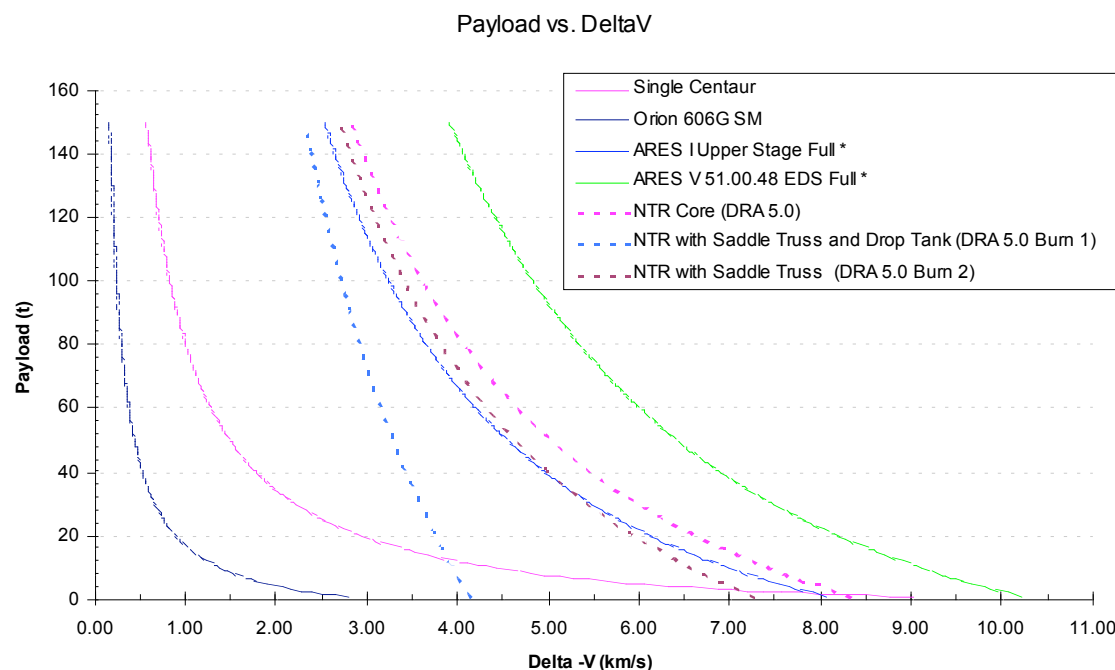
EELV Centaur Upper Stage



Ares V Earth Departure Stage (EDS)



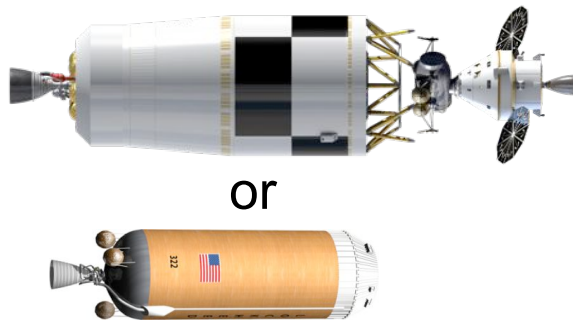
DRA 5 Nuclear Thermal Rocket (NTR)





# Flexible Path Transportation Elements

## Initial and then Modest Capability



or



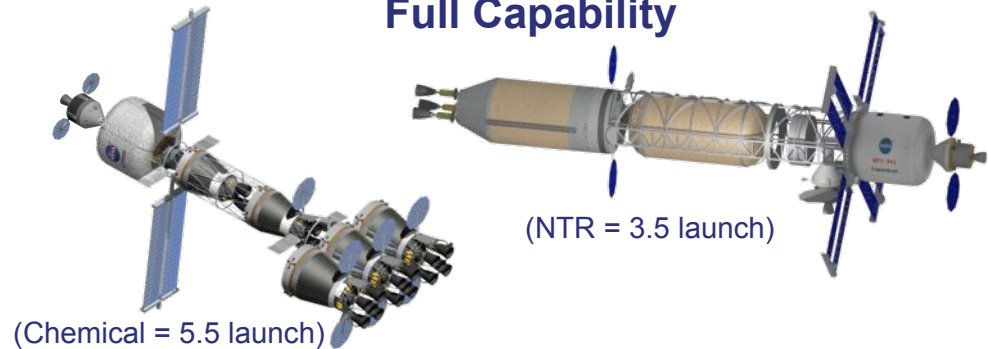
- Orion with Upper Stage (Centaur and then EDS)
- Missions to Lunar Orbit, Lagrange Points and nearby NEOs
- Completely Expendable
- Integration in Earth Orbit, independent of ISS



Infrastructure required for Scenarios

- Upper stage deployed in orbit via EELV, then Ares V or heavy lift equivalent
- Crew and Orion deployed via Ares I or equivalent
- Alternate is human-rated Ares V-class vehicle to gain single launch for modest missions

## Full Capability



- Mars Transit Vehicle (MTV) defined for 2009 DRA5 Mars Architecture Study (Chemical vs NTR)
- Supports missions to Mars Orbit (Phobos), Venus Orbit and less accessible NEOs
- Potentially reusable design (except for Orion elements and drop tanks)



Infrastructure required for Mission Propellant and Outfitting

# ***Flexible Path: Enabling Technology Needs***

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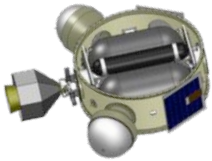


- ◆ Zero boil-off technology ( $\sim 0.5\%$  / month boil off at 0.1 kw/Mt) for EDS
- ◆ Zero-g cryogenic fluid transfer capability for filling EDS's while in orbit
- ◆ In-space NTR transfer stage ( $I_{sp} = 900$  secs)
  - possibly not required depending on cryo-fluid transfer trades
  - definitely enhancing technology
- ◆ Closed-loop ECLSS technologies
- ◆ Human radiation and zero-g countermeasures robust enough to enable 2-year missions
- ◆ Proximity/contact operations technologies for  $\mu$ -gravity rendezvous with NEOs (Unique for Scenario E)

# Robotic Precursors & Coupled Missions



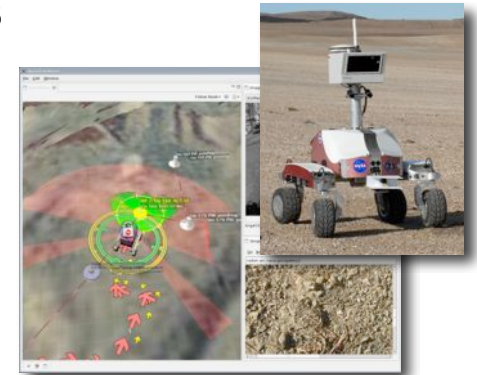
Precursor and concurrent robotic missions are integrated and enabling components of the Flexible Path Scenario



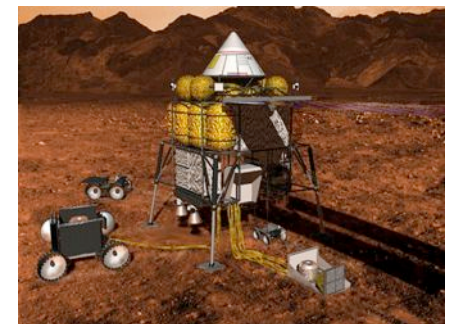
- ◆ NEO Precursors to validate physical characteristics and landing/anchoring methodology

- ◆ Robotic surface exploration of Mars, and Venus (lander / rover / aircraft / balloon)

- ◆ Mars surface sample return system:
  - to gather samples for piloted Phobos mission
  - to understand future human Mars landing site biology/toxicity/water



*These do not preclude other robotic missions to Moon and other destinations*

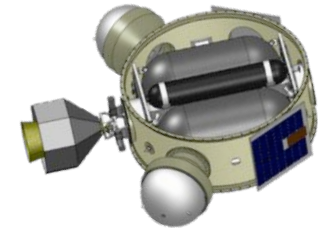


# NEO Precursor Mission Objectives

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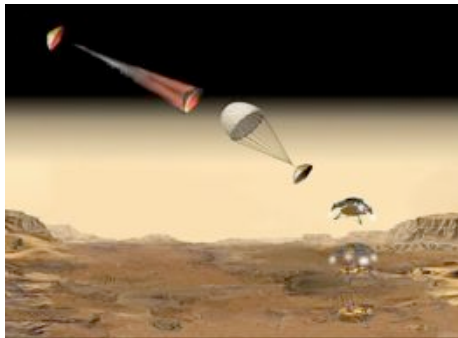


- ◆ Prior to sending a piloted mission to a NEO, additional characterization of the target is required
- ◆ Obtain basic reconnaissance to assess potential hazards to vehicle and crew
- ◆ NEOs could be binary systems, rapid rotators, potentially active surfaces, etc.
  - Non-benign surface morphologies
- ◆ Assess surface for future activities to be conducted by the Orion crew and payload
  - proximity operations
  - surface operations
  - sample collection



Atlas V launch

# Mars Sample Return (MSR) Lander Sampler

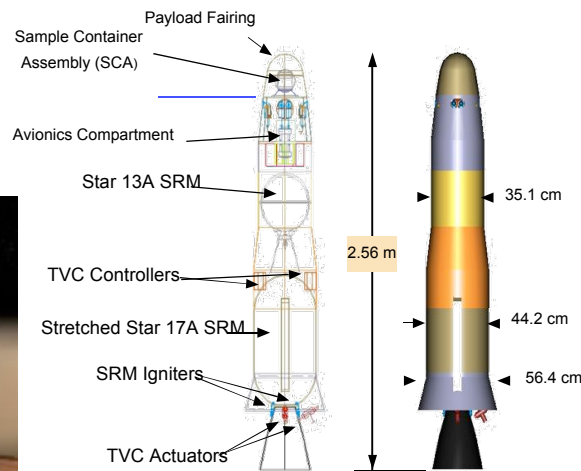


- EDL system (MSL skycrane)

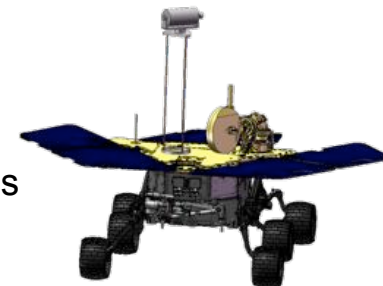
- Rendezvous with Human Phobos mission for Earth return



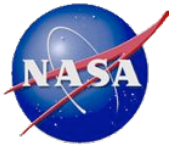
- Atlas V launch



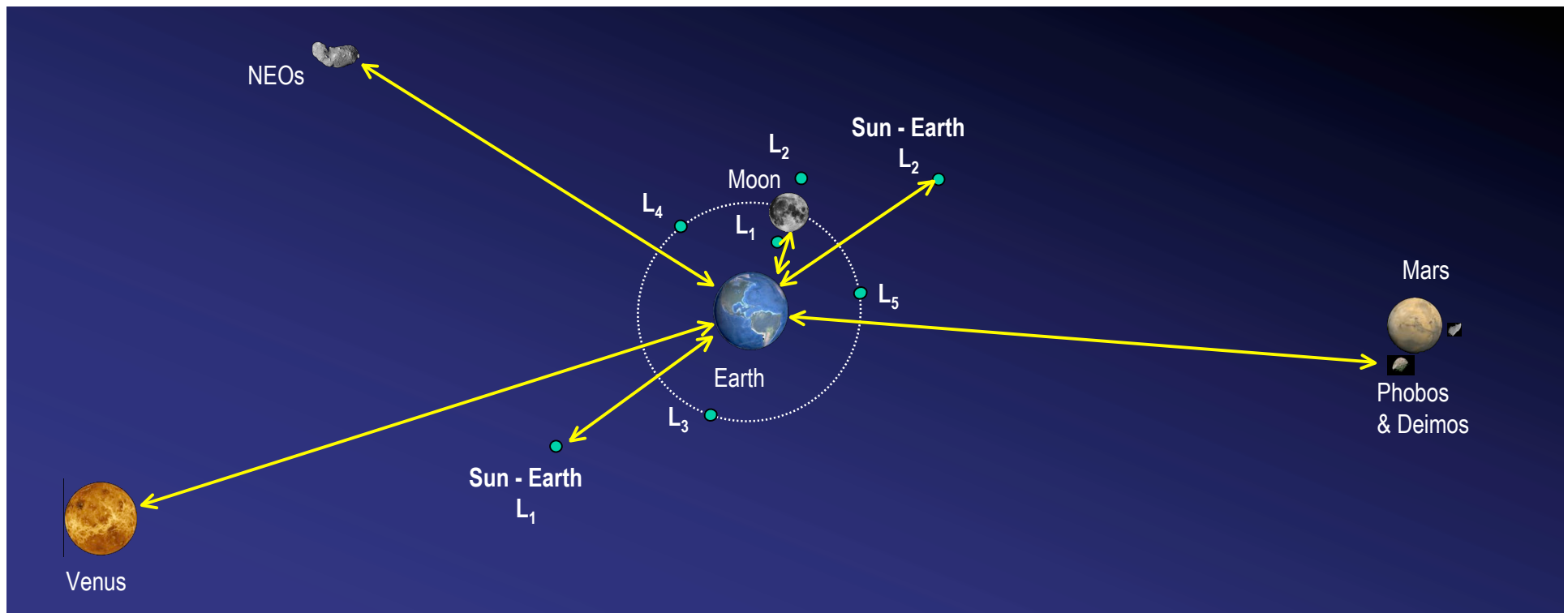
- Lander with Rover and Snatch n' Grab
  - Carries sampling Rover and Ascent Vehicle, packages samples
  - Uses Phoenix arm/scoop as sampling



# *Recommended Scenario Approach*



- Cost constrained Weighted – Discussion
- Destination Benefit Weighted – Discussion



# Flexible Path Scenario Assessment Summary

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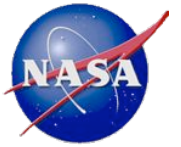


- **Objective**
  - A flexible scenario that focuses on a variety of mission destinations in an integrated campaign
  - Focuses on low-g missions only and does not preclude humans to a planetary surface
  - The campaign culminates in a human Phobos and Mars sample return mission in the 2024 - 2030 timeframe and provides the basis for a future Mars human landing (Scenario C/D)
- **Scope of Assessment**
  - This study effort is an initial integration of a variety of design reference missions into a cohesive scenario for the flexible exploration of the inner solar system through human and robotic systems. The following still need to be undertaken:
    - ✓ Numerous detailed trade studies
    - ✓ Comprehensive life cycle cost analysis (technology, precursors, demonstrations, etc.)
    - ✓ Integrated development and implementation plan
- **Flexible Path Mission Evolution**
  - U.S. leading robust human exploration missions
  - Regular crewed deep space missions that provide critical knowledge and experience
  - Scenario E evolves into Scenario C/D after Mars Flyby/Phobos or as resources are available for lander and surface systems development

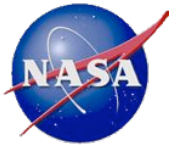
# Scenario E Team



<b>David Korsmeyer</b>	Dan Mazanek
Rob Landis	Rob Falck
Gabe Merrill	Frank Bauer
Leon Gefert	Dan Adamo
Rob Adams	John Casani
Richard Mattingly	Ted Sweetser
Doug Comstock	Steve Oleson
Eameal Holstien	



# ***Backup***



## ***Scenario E) Flexible Path Mission Sequence***

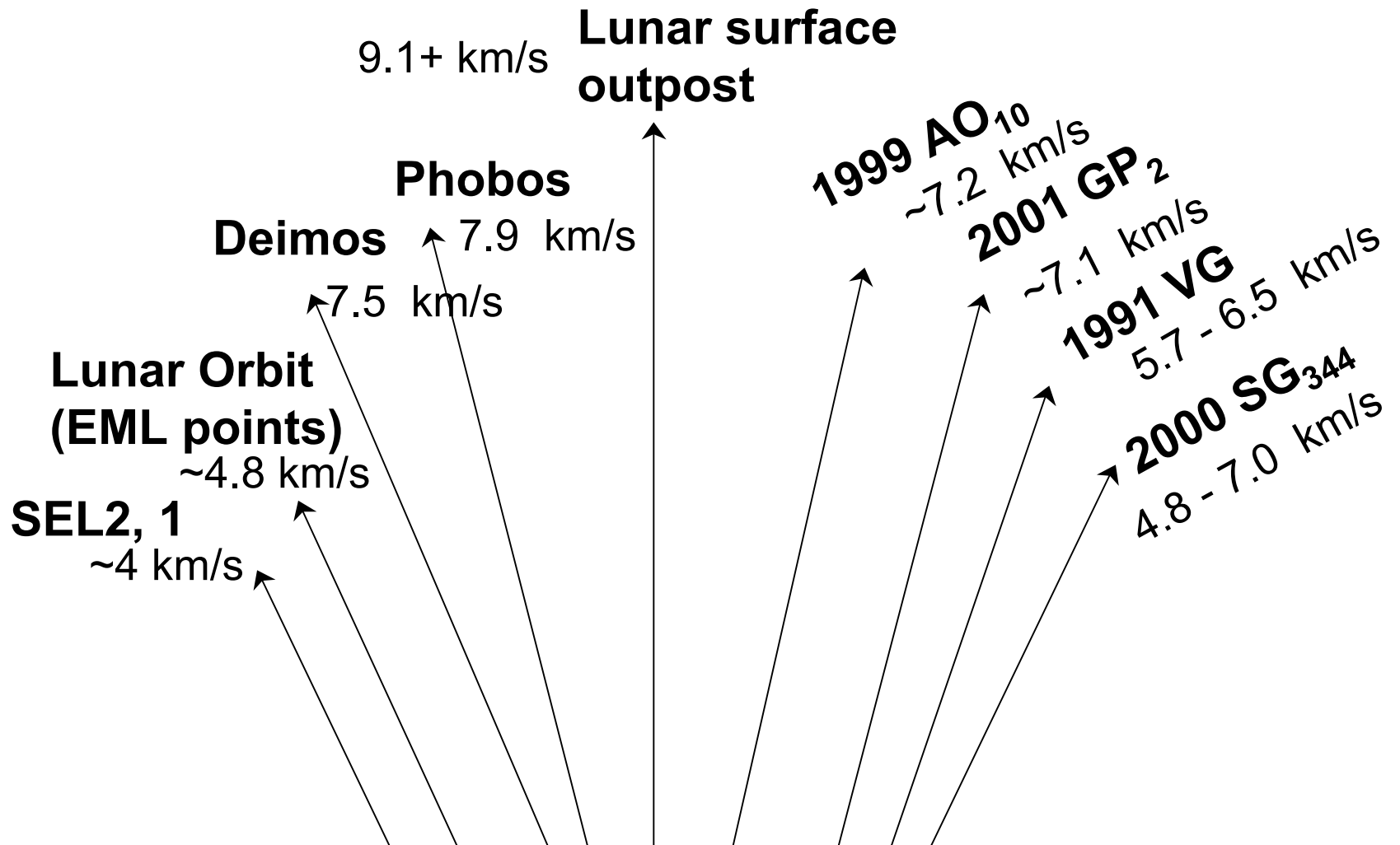
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### ***Sequence for Scenario***

1. Unpiloted mission to Sun-Earth L1 for system test (or lunar flyby)
2. Piloted mission to lunar flyby and/or to Earth-Moon L1
3. Mission to Sun-Earth L2 to service science assets
4. Mission to Sun-Earth L1 to experience the interplanetary radiation environment
5. Several missions to NEOs to rendezvous and return samples
6. Flyby mission to Mars with telerobotic operation of surface assets
7. Mars Phobos rendezvous and Mars/Phobos surface sample return
8. ?Venus orbital mission, and balloon teleoperation

*Initial Operational Capability (IOC) is human presence  
in orbit of Mars or Venus*

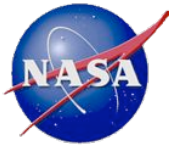
# $\Delta v_{tot}$ Comparisons for Lunar Surface/Orbit, Phobos, Deimos, and a few NEOs



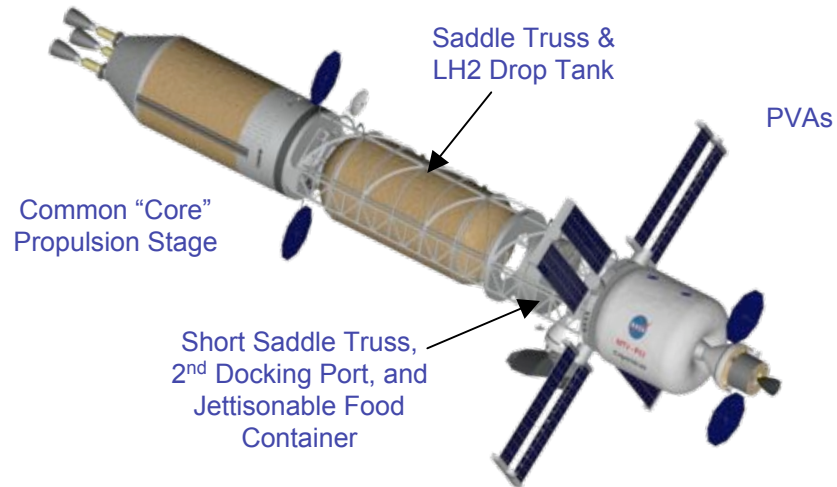
*\*for NEOs  $\Delta v$  depends on phasing of orbit and when mission is launched.*

# Design Reference Architecture 5.0

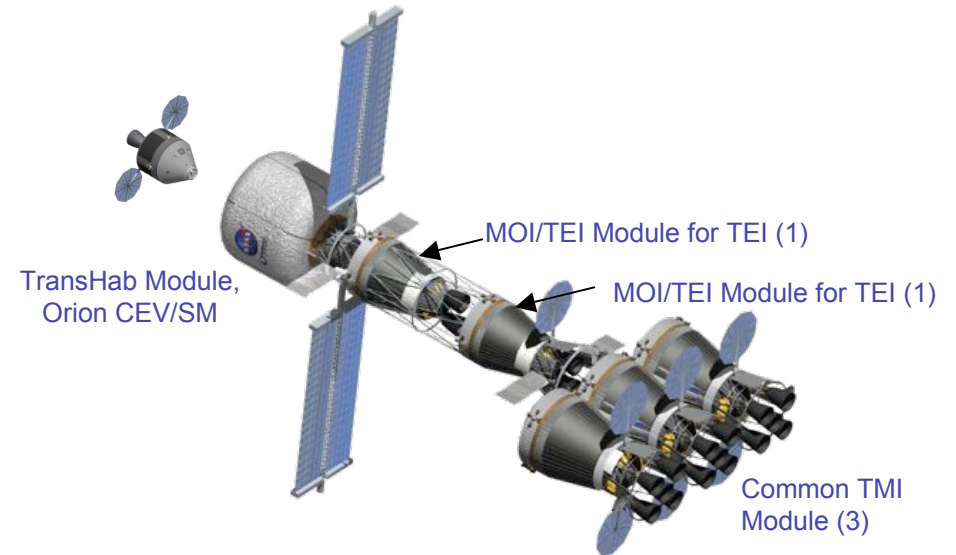
## NTR & Chemical Mars-Class Crew Vehicles



### 3.5 Launch NTR Crew Vehicle Elements



### 5.5 Launch Chemical Crew Vehicle Elements



# Orion Support of Flexible Path Missions



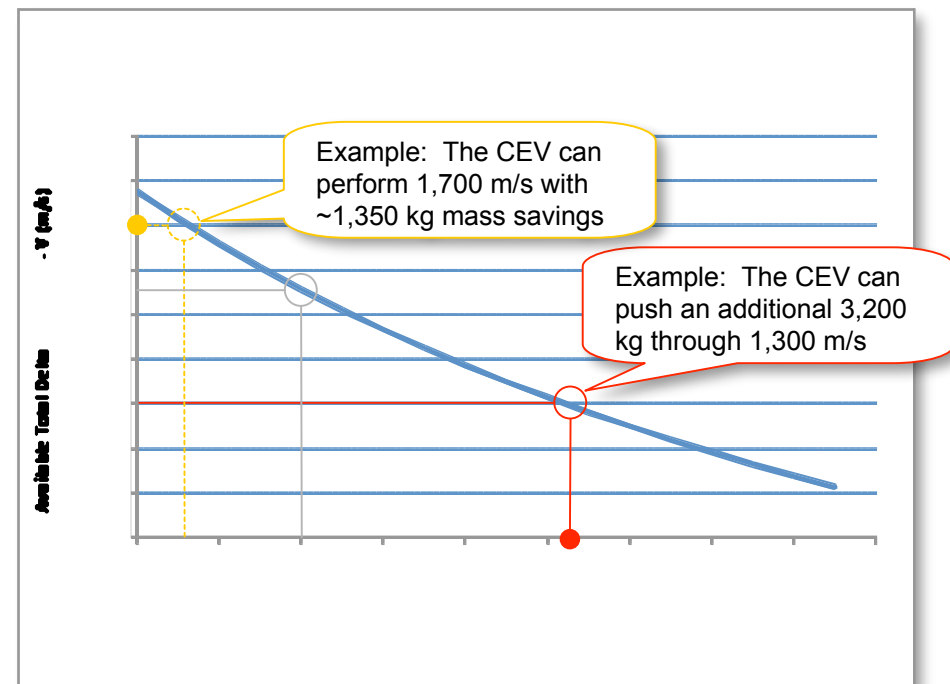
## ◆ “Lunar” Orion Capabilities

- Support of 4 crew for 18 days
- Provides  $\sim 1,550$  m/s total delta-v\*
- $\sim 1,500$  We power to other elements



## ◆ Flexible Path Mission Modifications

- Support of crew for 90+ days
  - Consumables
  - Habitation / exercise
- Radiation protection for longer duration deep-space mission



\* Total delta-v available dependent on propellant load and vehicle mass

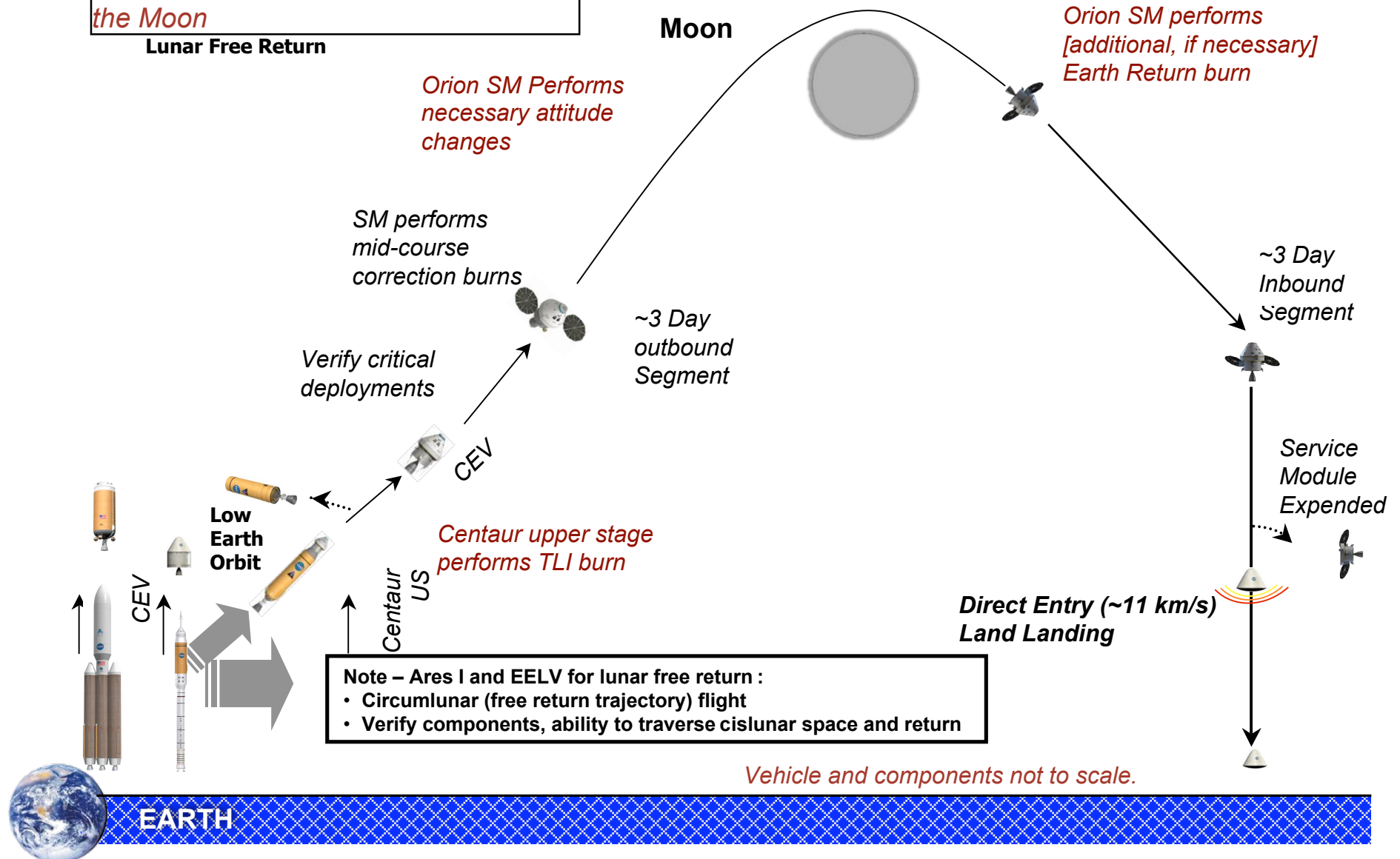
# Ares I and EELV Lunar Free Return

Centaur US / Orion SM provides Earth Departure, and Earth Return  $\delta V$



*Unpiloted and Piloted test flight around the Moon*

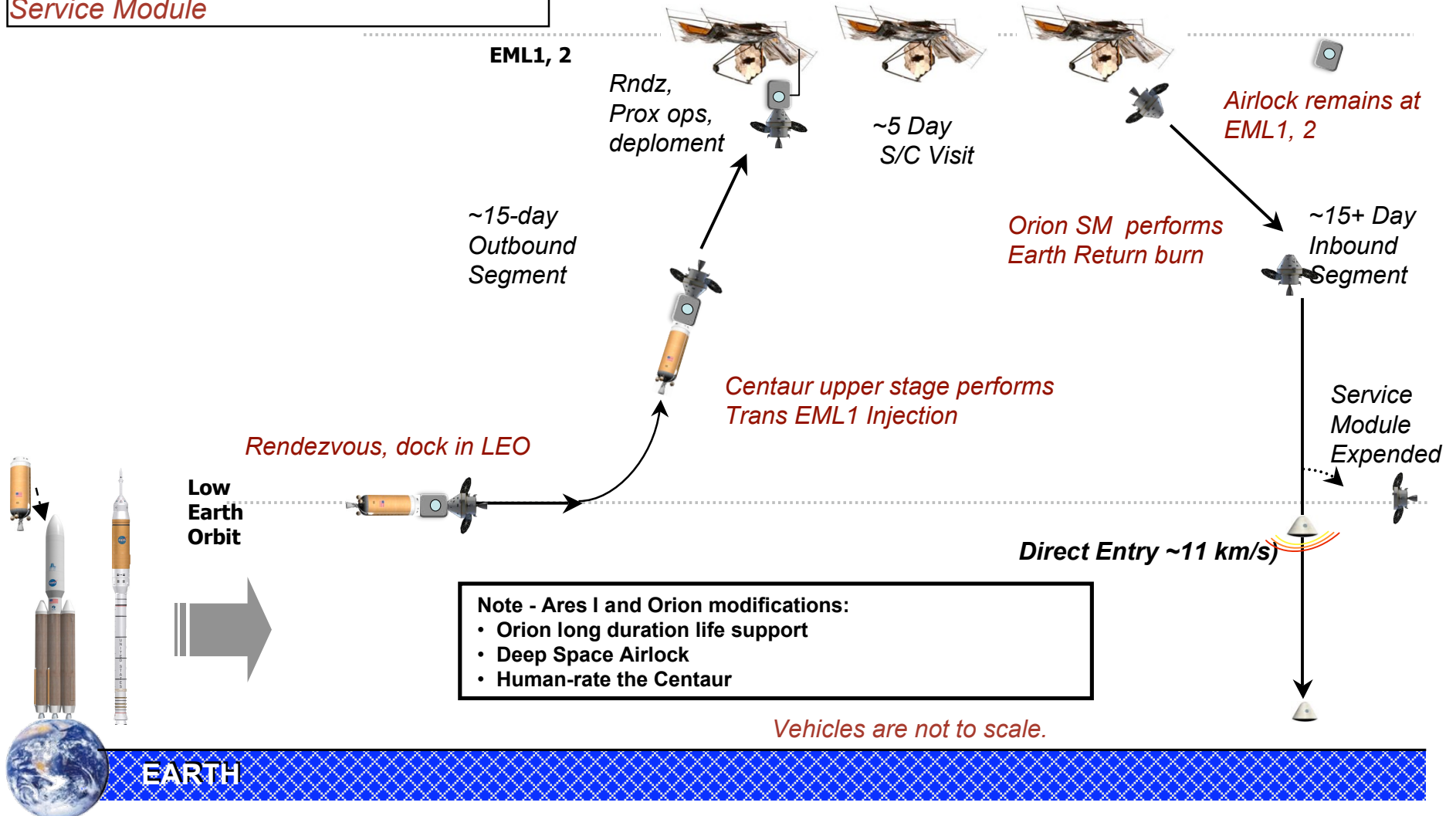
**Lunar Free Return**



# Earth-Moon L1 (EML1) Mission Deployment of Telescope, or other Science Spacecraft



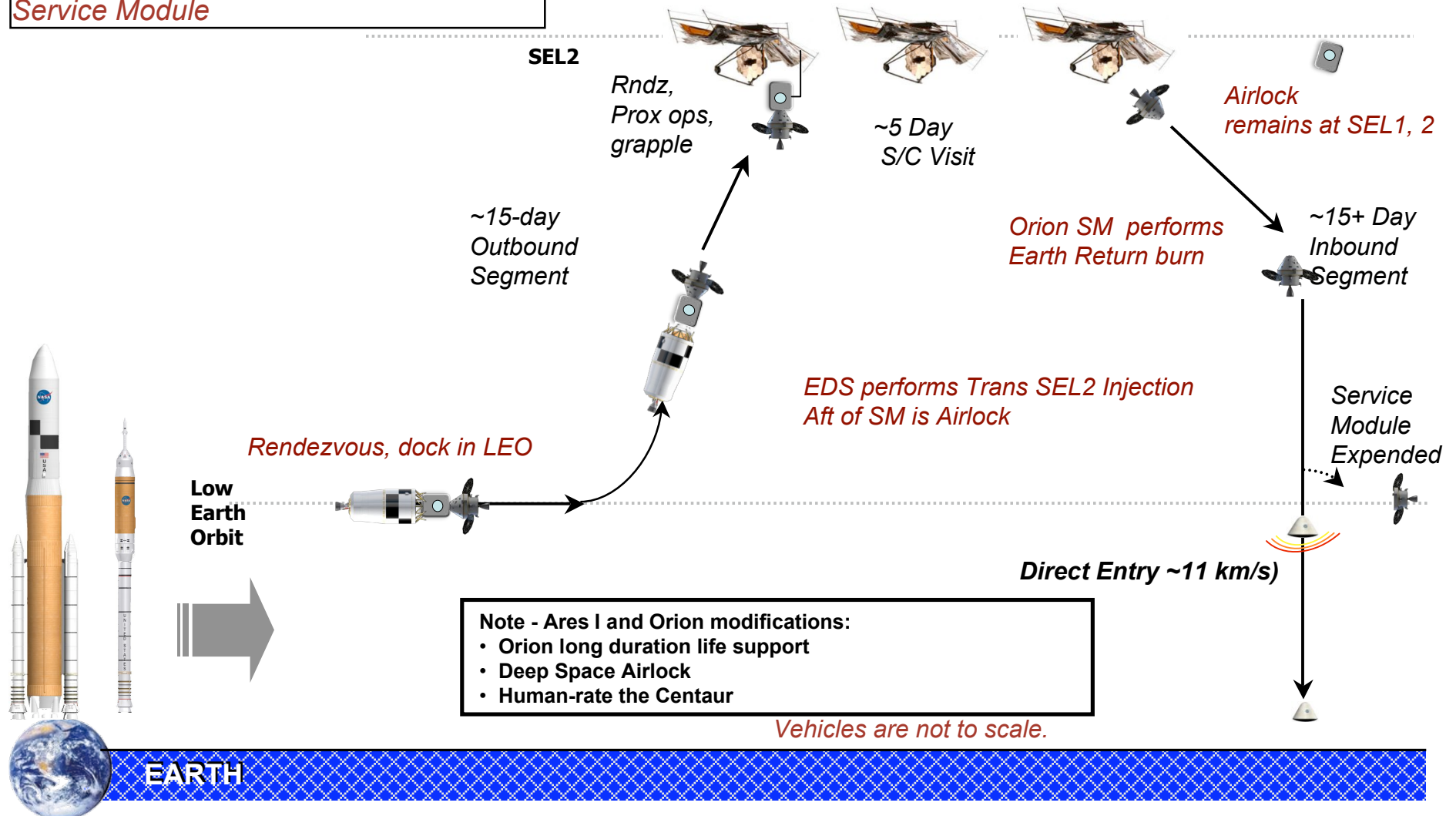
*Assumes 2-3 Crew  
Multiple EVAs  
Hardware stored in Airlock and aft-end of  
Service Module*



# Sun-Earth L1, 2 (SEL1, 2) Mission Servicing [Telescope, or Other Science Spacecraft]

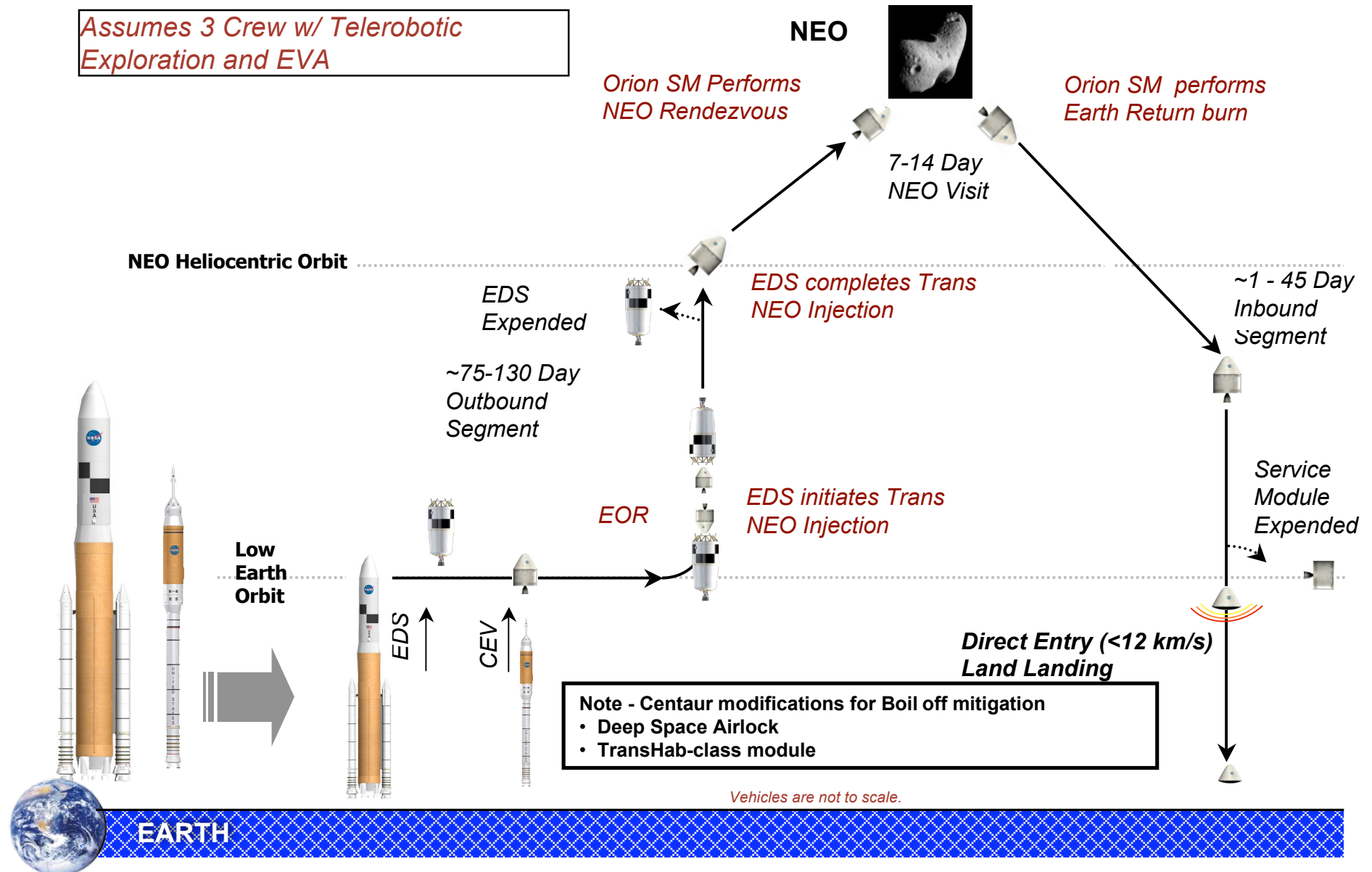


*Assumes 2-3 Crew  
Multiple EVAs  
Hardware stored in Airlock and aft-end of  
Service Module*





*Assumes 3 Crew w/ Telerobotic Exploration and EVA*



# Near-Earth Object (NEO) Crewed Mission – single Ares IV

EDS / Orion SM provides Earth Departure, NEO Arrival, and Earth Return  $\Delta V$



*Assumes 2 Crew w/ Telerobotic Exploration and EVA;  
Later EVA to retrieve samples if not collected by initial EVA.*

**NEO Heliocentric Orbit**

*EDS & Orion SM  
Performs NEO  
Rendezvous*



**NEO**

*Orion SM performs  
Earth Return burn*

*EDS Expended*

**7-14 Day  
NEO Visit**

**~45+ Day  
Inbound  
Segment**

**~90-130 Day  
Outbound  
Segment**

*EDS performs Trans  
NEO Injection with a  
large margin*

**Service  
Module  
Expended**

**Low  
Earth  
Orbit**

**EDS, CEV**

**Direct Entry (<12 km/s)**

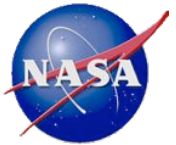
**Note - Ares V and Orion modifications:**

- Ares V human rating
- Deep Space Airlock
- TransHab-class module

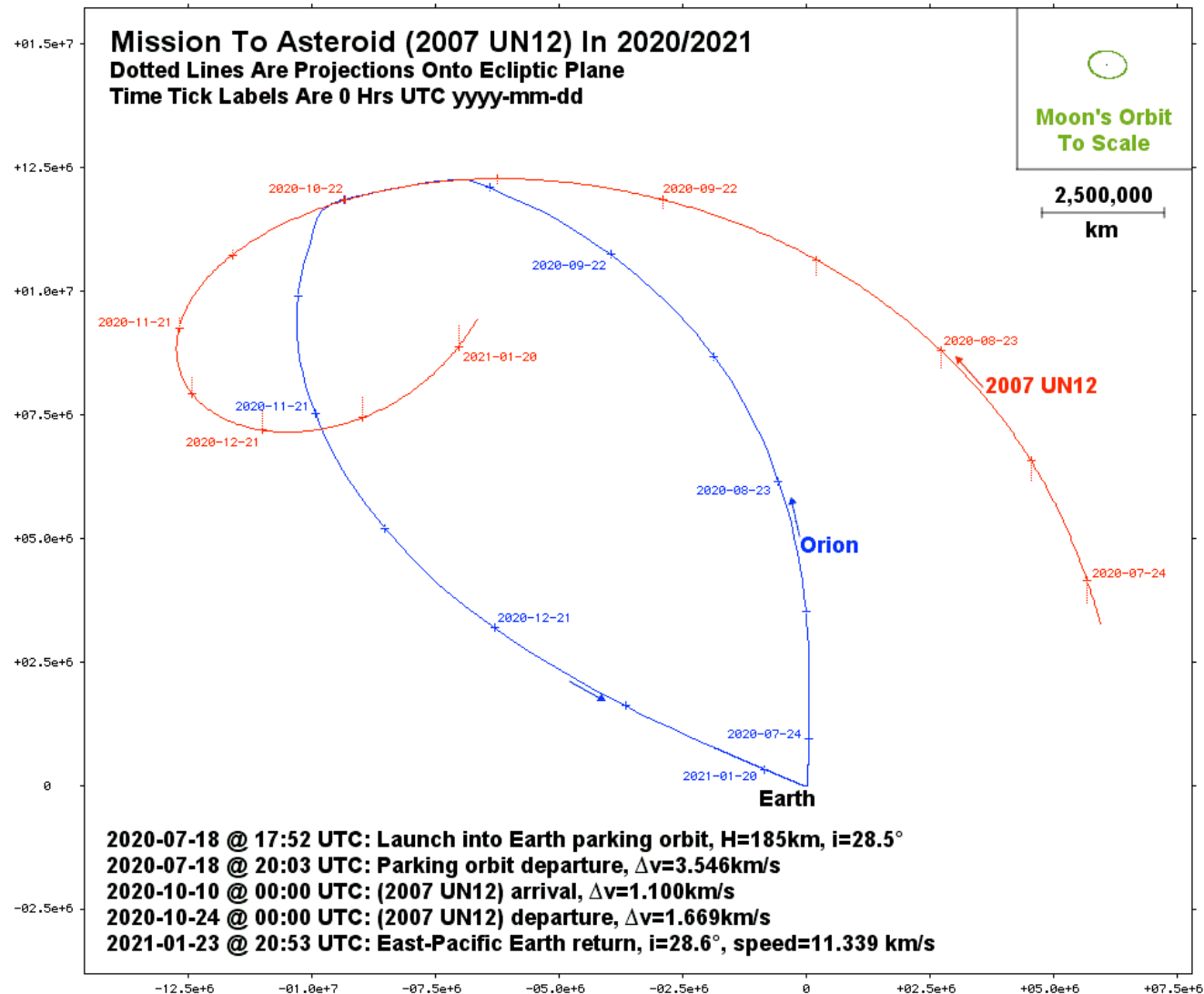
*Vehicles are not to scale.*

**EARTH**



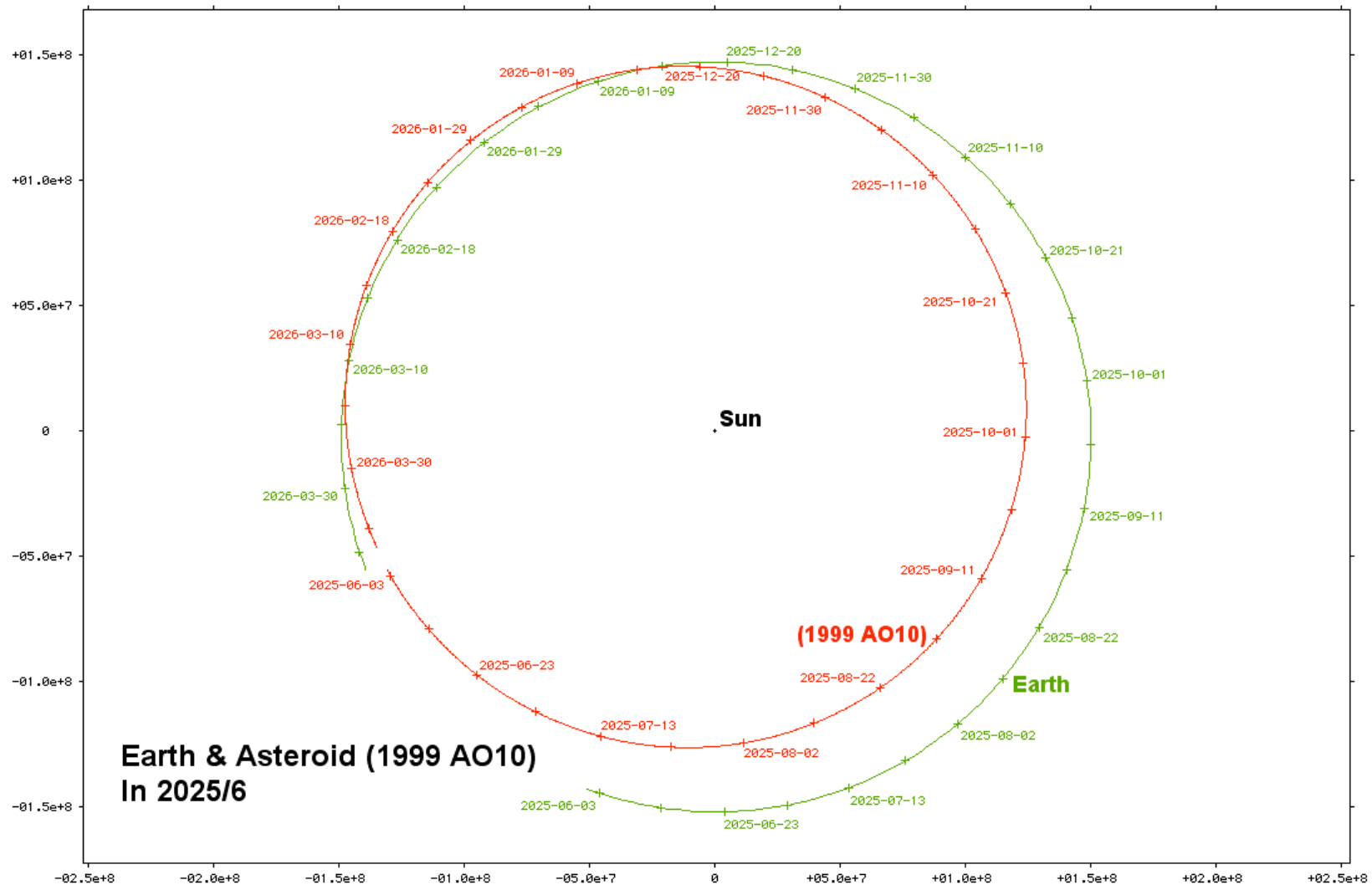
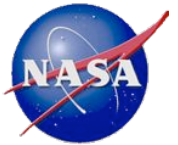


# 190-day Mission to 2007 UN<sub>12</sub> (late-2020)



Km Units View From  $Y=0.0^\circ$ ,  $P=0.0^\circ$ ,  $R=45.0^\circ$   
Earth-Centered J2KE Coordinate System  
Visit to (2007 UN12): Earth departure segment

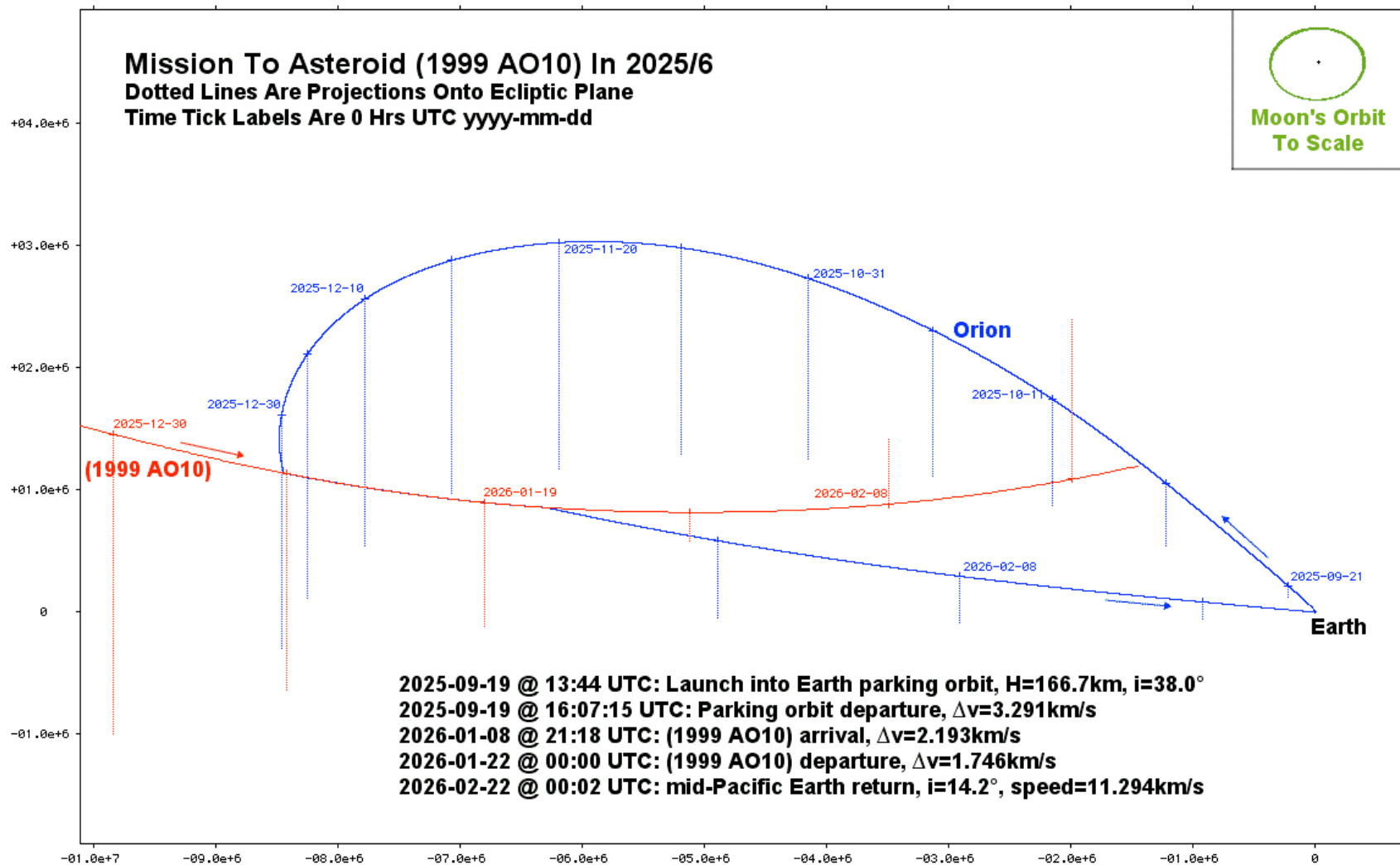
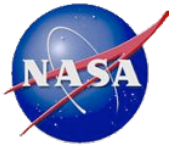
# Mid-Volume (Ares 5 – Single Launch) 150-Day Mission to 1999 AO<sub>10</sub> Heliocentric Trajectory Plot for Mission



Earth & Asteroid (1999 AO10)  
In 2025/6

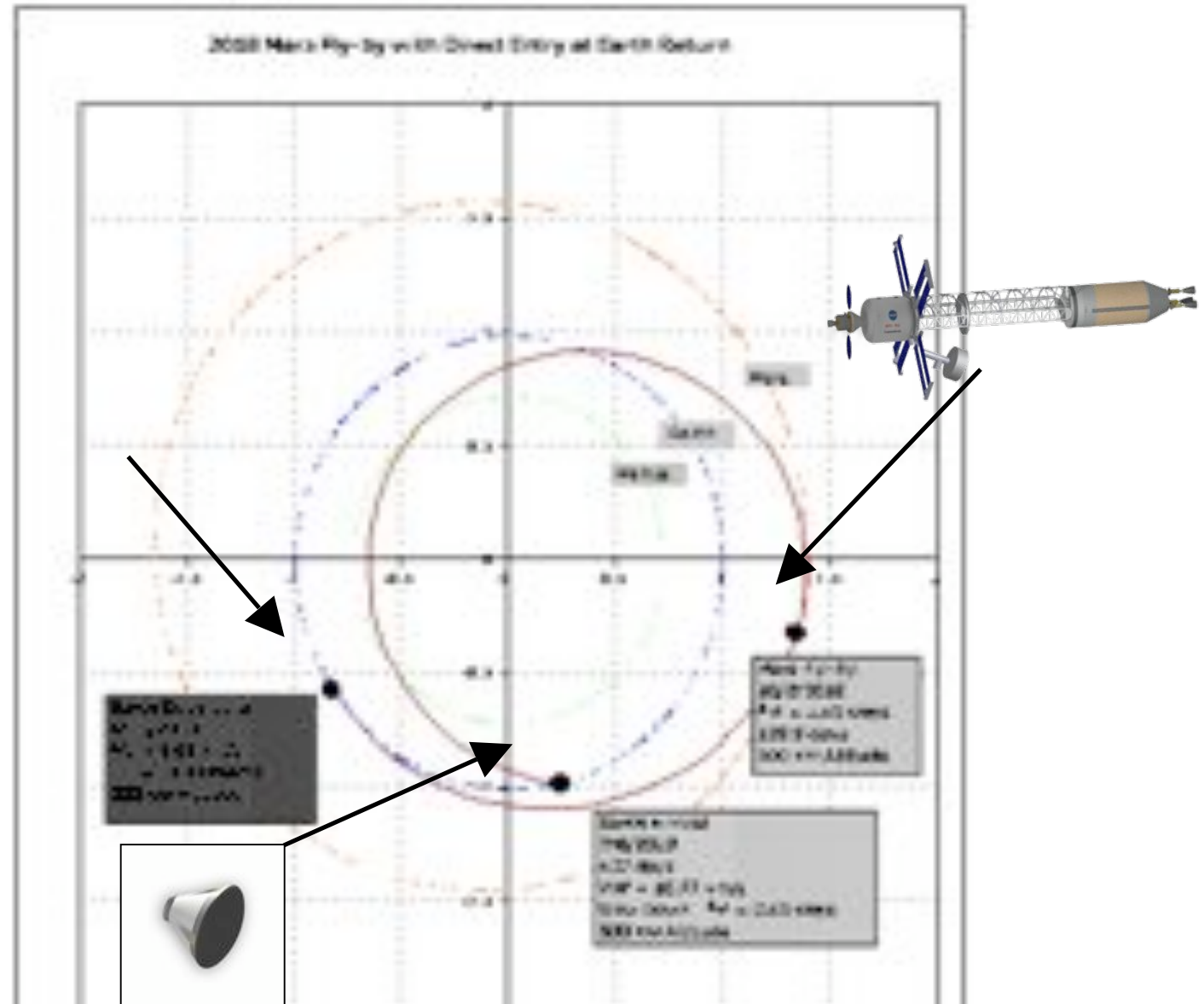
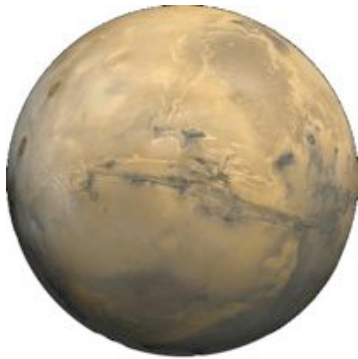
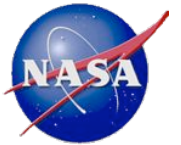
Km Units View From Y= 0.0°, P= 0.0°, R= 0.0°  
Sun-Centered J2KE Coordinate System  
Visit to (1999 AO10)

# Mid-Volume (Ares 5 Single Launch) 150-Day Mission to 1999 AO<sub>10</sub> Earth-fixed Trajectory Plot for Mission

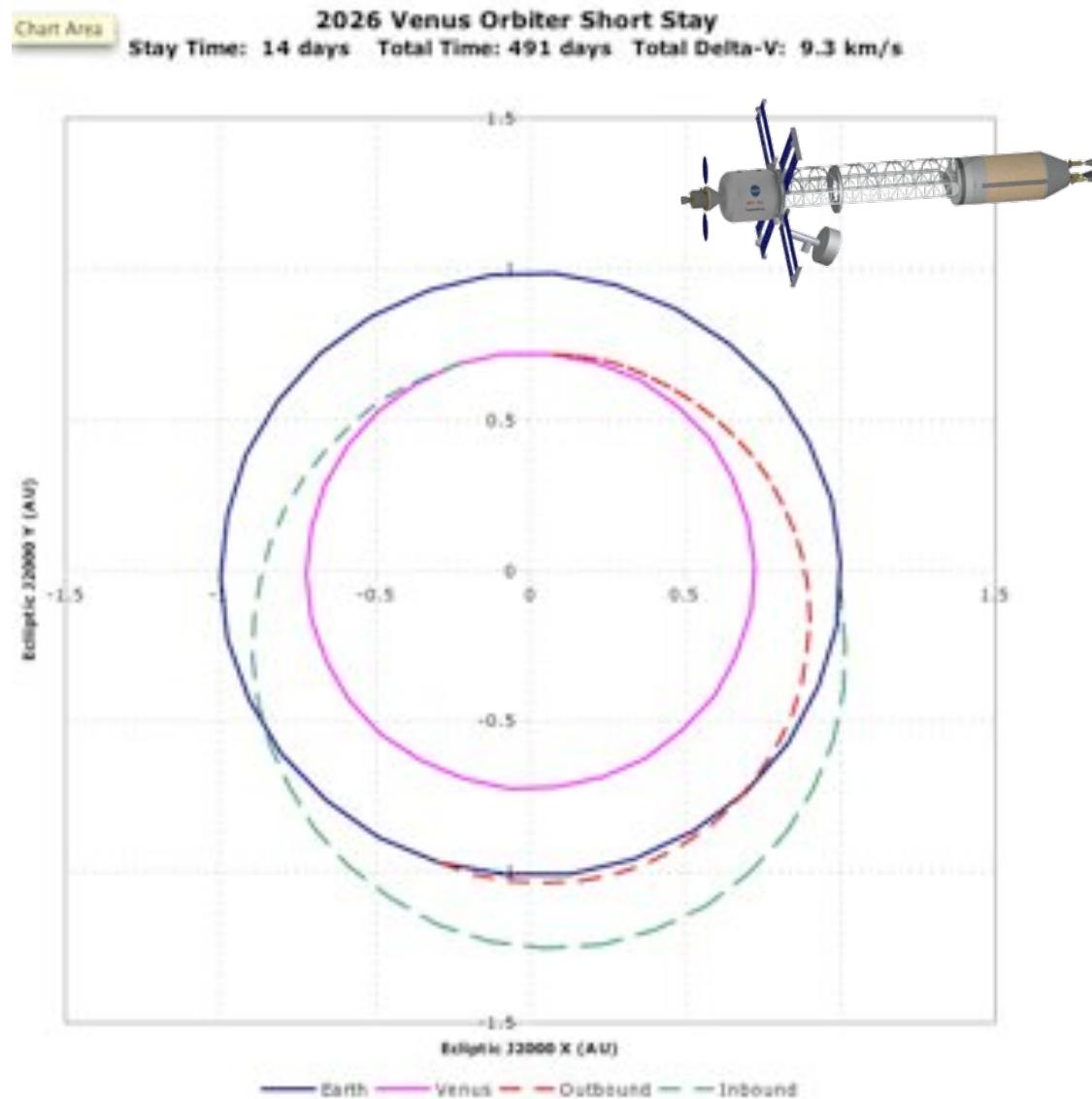


Km Units View From  $Y=0.0^\circ$ ,  $P=0.0^\circ$ ,  $R=45.0^\circ$   
Earth-Centered J2KE Coordinate System

# Mars Flyby with TeleRobotic Surface Operations



# Venus Rendezvous with Telerobotic Operations

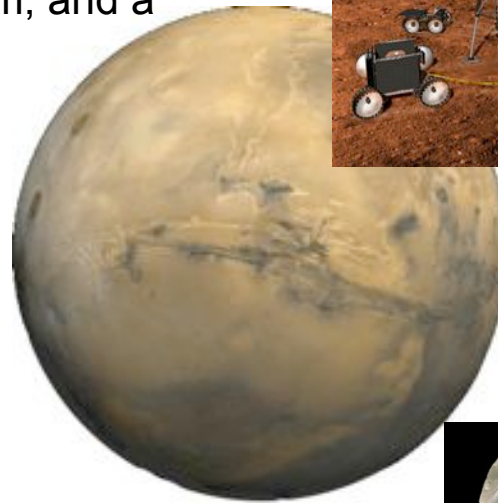
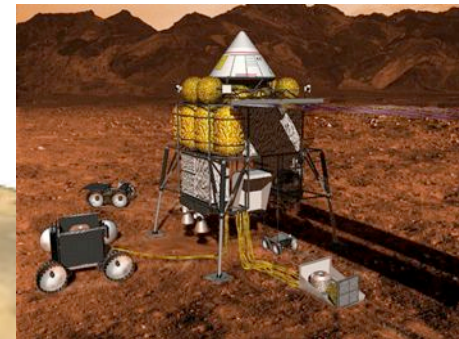
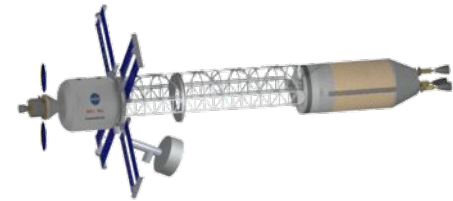


# Phobos Rendezvous and Mars Sample Return Mission



## ◆ Mission Profile

- Piloted Mission to Phobos/Deimos
  - Rendezvous and explore Phobos and Deimos
  - Collect surface and subsurface samples
- Pre-deploy 4.5MT and 12MT Surface Sample Return systems at 2 locations on Mars via Ares V launch
  - Explores subsurface to 10 m depth at several local places (<1 km) at a single-landed location
  - Gather 2 surface samples of 500gm, and a single sub-surface sample of 1kg



\* Total delta-v available dependent on propellant load

# Phobos Mission Concept of Operations



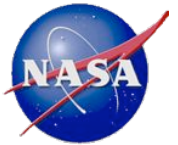
## Assembly in LEO multiple launches

- ◆ Launches for Re-fuel Final EDS
- ◆ Launch 1 NTR / BNTR Core Stage ~ 120t
- ◆ Launch 2 Saddle Truss and Drop Tank ~ 120t
- ◆ Launch 3 TransHab, Logistics, Excursion Vehicle ~ 40t
- ◆ Launch 3.5 Launch Orion (CM and SM) ~ 22t

IMLEO = ~ 301t + EDS Kick Stage

Total = ~ 580t + Inter-stage (needs to be sized assumed ~ 10t)





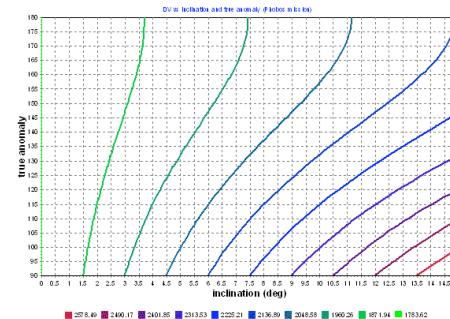
# Phobos Mission Delta-V Budget

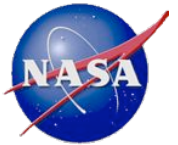
Transfer to Mars 3643km x 37186 km Orbit with  $0 < \text{Inclination} < 15$

	Delta-V Budget Available	Minimum Homann
TMI	5.16	3.6
MOI	1.14	0.7
TEI	4.2	3.6

Transfer to Phobos / Deimos (Transfer Durations need to be validated)

Mars Moons Exploration		
	worst	best
P	2.436	1.958
D	1.94299	1.646
P-D	3.0379	2.65





# Phobos Mission Habitation and Logistics

- ◆ 3 Crew for 780 day duration
- ◆ 2.45 kg of food/day + 5t maintenance and spares (M&S)
- ◆ ~ 100 m<sup>3</sup> pressurized volume Trans Hab at 15t including:
  - Power system
  - Radiation protection
  - Outfitting

Thab Sizing			
Mars Point Designs	mass	volume req'd	
6	29000	180	
4	22600	120	
Diff per crew	3200		
mass per crew	5241.667		
Scale by mass per crew		scale by diff per crew	Average
3	15725	19400	17562.5
2	10483.33	16200	13341.67
1	5241.667	13000	9120.833
Informed Approximation		req'd press volume	
Med Sized Thab	15000	100	
Smaller Sized T Thab	10000	50	
Sanity check: LSS Hab is 56 m <sup>3</sup> volume and < 10t with power			



Note: Press Volume based on  
 $6.67 \cdot \ln(\text{duration}) - 7.79$  Ref. Rudisill et al

# Phobos Mission Trans Mars Injection (TMI)

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## ◆ Burn 1: Kick Stage

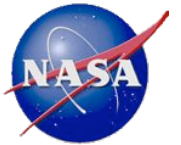
- Ares v EDS burns 253.05 t propellant
- 2.45 km/s Delta – V
- Payload 311t / inert stage mass 26.4t
- EDS and Inter-stage are staged (26.4t+10t)

## ◆ Burn 2: NTR

- NTR Burns 80t propellant
- 2.71 km/s Delta-V
- 10t propellant remaining
- Payload 147t / inert stage mass 75t

# Phobos Mission; Mars Orbit Injection (DSM / MOI)

---



## ◆ Burn 1: DSM or MOI

- NTR Burns 10t Propellant
- .406 km/s Delta-V
- Drop tank Staged
- Payload 137t / inert stage mass 75t

## ◆ Burn 2: MOI

- NTR Burns 15.5t Propellant
- .736 km/s Delta-V
- Payload 121.4t / inert stage mass 75t

# Mars/Phobos Mission Orbit Ops / TEI

---



- ◆ **Explore Mars' Moons (60 days)**
- ◆ **Rendezvous with MSR**
- ◆ **Jettison SM/Exploration Vehicle and anything else non-critical prior to return trip (only food for return and 1t M&S)**
- ◆ **Burn 1: TEI**
  - NTR Burns 58.5t Propellant
  - 4.2 km/s Delta-V
  - Drop tank Staged
  - Payload 39.2t / inert stage mass 56.7t
- ◆ **Orion CM direct Earth return**

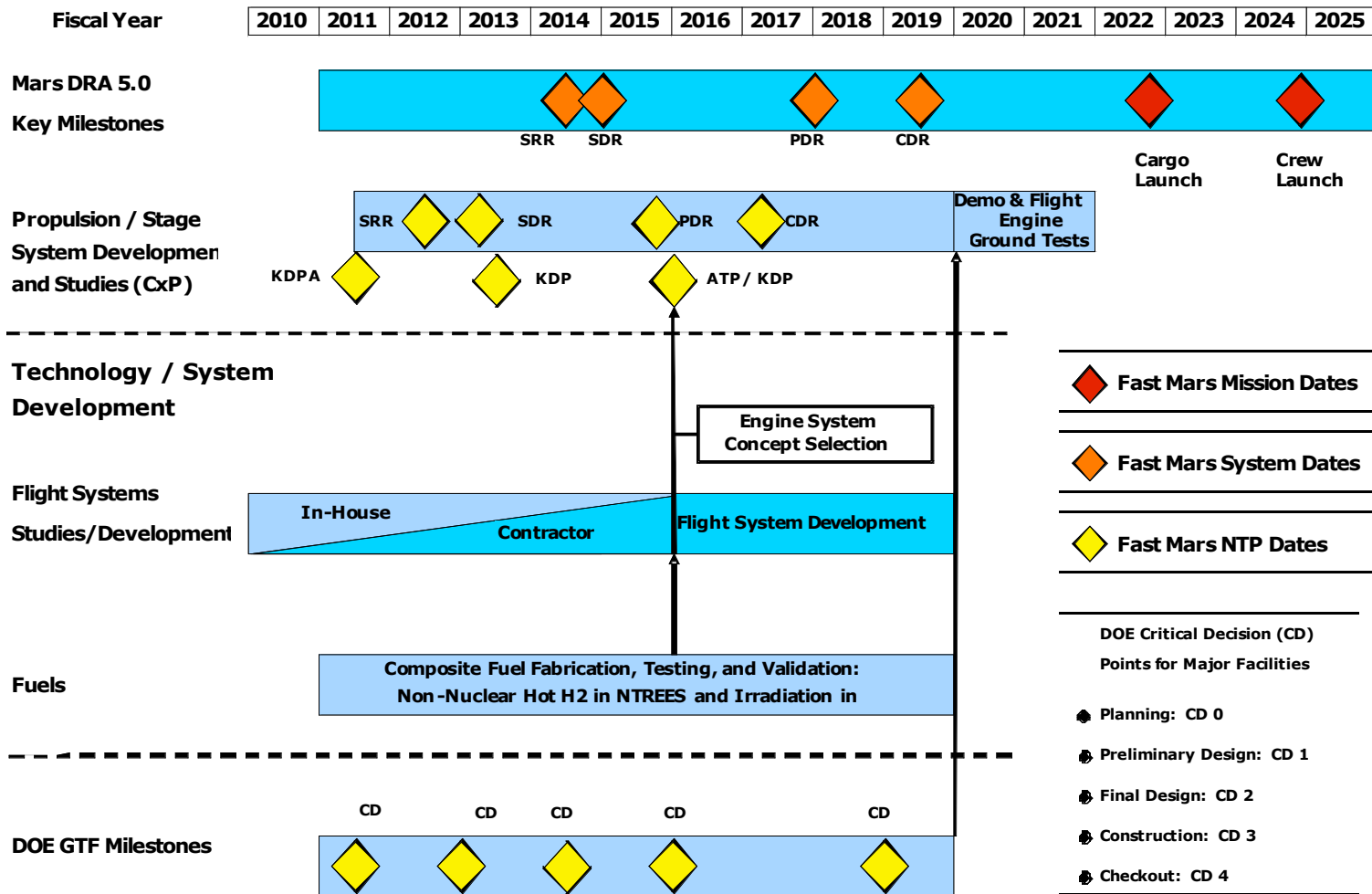


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# Technology Charts Backup

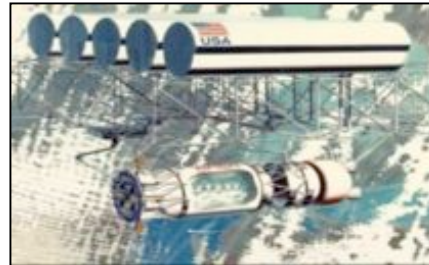
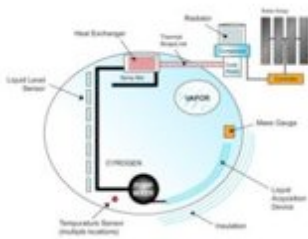
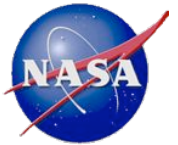


# Nuclear Thermal Propulsion Road Map



- Development Schedule Assumptions:**
- Previously Demonstrated NERVA Composite Fuel Selected as Baseline
  - Borehole Tunnel Testing Selected as Baseline (Simpler and Quicker Approach)
  - Fuel Element Validation Using Separate Effects Testing (MSFC NTREES Plus DOE/INL ATR)
  - Fuel Fabrication is Industry Led with DOE Support
  - Concurrent Engineering Instead of Slower Paced Serial Approach Used in Nominal Schedule

# In-Space (Zero-g) Cryogenic Fluid Management for Propellant Transfer Capabilities



## Zero-G Cryogen Capability - Technology Gaps

- Fluid Transfer
  - Tank chill and fill
  - Automated couplings and disconnects
- Fluid Management
  - Pressure control
  - Mass gauging
  - Liquid acquisition

## Status

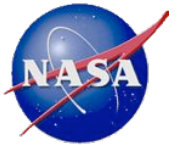
- Preliminary technology experiments have been conducted.
- Technology development roadmaps and cost estimates have been constructed
- ETD CFM Project (multicenter)
- Some technology development will be addressed though ground testing, however, and orbital flight demonstrator is recommended to mature the full compliment of cryogenic fluid management technologies in a systems integration standpoint and is thus a long lead, high cost item.

## Alternate Approaches

- Burning an integrated gaseous oxygen/hydrogen RCS thruster(s) before and during transfer to settle and provide some milli-g during transfer.
- Induce a rotational rate in the vehicle stack (this would require a long acquisition tube running from the fluid transfer interface to the far end of each tank)
- Change architecture element to handle function by transferring fuel by tank exchange

## Technology Performance Metrics

Required Capability	Figure of Merit			TRL
	Now	Near Term	Long Term	
Pressure Control	Propulsive settling	Controlled within +/- .5 psia in zero-g	Zero boil-off	4
Liquid Acquisition	Propulsive settling	98% expulsion efficiency w. LO2, CH4, & xenon	98 % expulsion efficiency w. LH2	3
Mass gauging	Propulsive settling Book keeping	3 -5% accuracy in zero-g w.o. settling	1% accuracy in zero g	2-4
Transfer and Distribution	None	Not TRL = 6 until flight experiment performed	92-94% o-g transfer efficiency	3



# Transit Habitat (6 crew)

## Description

The Mars Transit Habitat is the element in which the crew lives for the round trip between Earth and Mars. This habitat is a part of the Mars Transfer Vehicle. The MTV and MTH always remain in the space environment. Whether the transit habitat is constructed using rigid body or inflatable technology will need to be determined by detailed engineering analysis. However it is assumed that the MTH will share as many systems as pragmatically possible with the Mars Surface Habitat. The rationale behind maximizing the commonality between these two elements (one that operates in a zero-g environment and the other that operates in a 1/3-g environment) is driven by the desire to lower the development costs as well as to reduce the number of systems that astronauts would have to learn to operate and repair. An even more critical assumption is that the systems comprising the transit habitat (and SHAB) would be largely based on hardware design and reliability experience gained by ISS operations, as well as long-duration surface habitat operations on the lunar surface (i.e., lunar outpost), which would precede any Mars campaign.

## Power

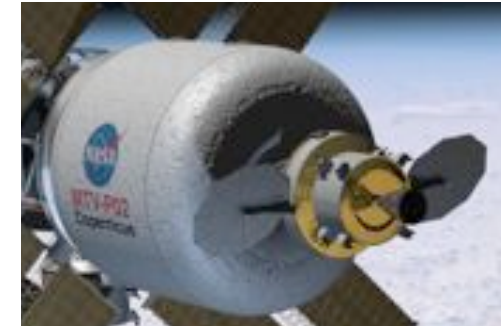
Maximum Generation Capability (W)	60 kW	Energy Storage Capacity (W-hr)	TBD
Active Average Day Requirement (W)	TBD	Active Average Eclipse Requirement (W)	TBD
Standby Average Day Requirement (W)	TBD	Standby Average Eclipse Requirement (W)	TBD

## Volume

Pressurized Volume (m <sup>3</sup> )	TBD
Habitable Volume (m <sup>3</sup> )	TBD
Airlock Volume (m <sup>3</sup> )	TBD

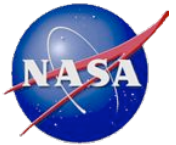
## Comments

Power  
Three regenerative H<sub>2</sub>/O<sub>2</sub> regenerative fuel cells for energy storage  
400 m<sup>2</sup> dual articulated GaAs solar arrays with assumed 20 percent efficiency. Maximum power generating capacity is estimated at Mars orbital radius



## Mass Breakdown Structure

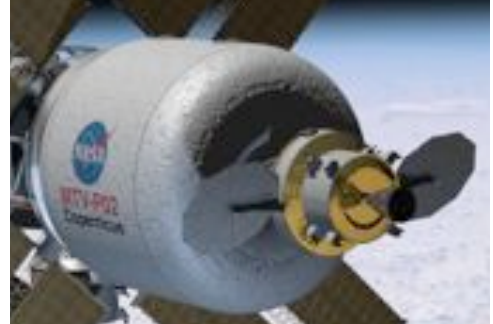
1.0 Structure	2018	kg
2.0 Protection	1257	kg
3.0 Propulsion	0	kg
4.0 Power	5835	kg
5.0 Control	0	kg
6.0 Avionics	287	kg
7.0 Environment	3949	kg
8.0 Other	4707	kg
9.0 Growth (30%)	4810	kg
<b>Dry Mass</b>	<b>22863</b>	<b>kg</b>
10.0 Non-Cargo	0	kg
11.0 Cargo	6058	Kg
<b>Inert Mass</b>	<b>28921</b>	<b>kg</b>
12.0 Non-Propellant	13230	kg
13.0 Propellant	0	kg
<b>Total Mass</b>	<b>42151</b>	<b>kg</b>



# Transit Habitat (4 crew)

## Description

The Mars Transit Habitat is the element in which the crew lives for the round trip between Earth and Mars. This habitat is a part of the Mars Transfer Vehicle. The MTV and MTH always remain in the space environment. Whether the transit habitat is constructed using rigid body or inflatable technology will need to be determined by detailed engineering analysis. However it is assumed that the MTH will share as many systems as pragmatically possible with the Mars Surface Habitat. The rationale behind maximizing the commonality between these two elements (one that operates in a zero-g environment and the other that operates in a 1/3-g environment) is driven by the desire to lower the development costs as well as to reduce the number of systems that astronauts would have to learn to operate and repair. An even more critical assumption is that the systems comprising the transit habitat (and SHAB) would be largely based on hardware design and reliability experience gained by ISS operations, as well as long-duration surface habitat operations on the lunar surface (i.e., lunar outpost), which would precede any Mars campaign.



## Power

Maximum Generation Capability (W)	38 kW	Energy Storage Capacity (W-hr)	TBD
Active Average Day Requirement (W)	TBD	Active Average Eclipse Requirement (W)	TBD
Standby Average Day Requirement (W)	TBD	Standby Average Eclipse Requirement (W)	TBD

## Volume

Pressurized Volume (m <sup>3</sup> )	TBD
Habitable Volume (m <sup>3</sup> )	TBD
Airlock Volume (m <sup>3</sup> )	TBD

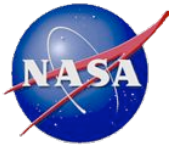
## Comments

Power  
Three regenerative H<sub>2</sub>/O<sub>2</sub> regenerative fuel cells for energy storage  
320 m<sup>2</sup> dual articulated GaAs solar arrays with assumed 20 percent efficiency. Maximum power generating capacity is estimated at Mars orbital radius

## Mass Breakdown Structure

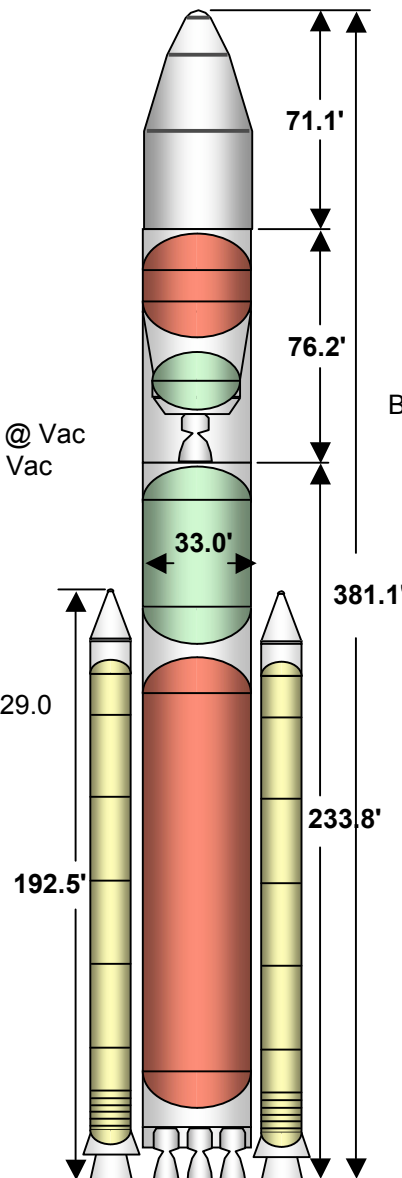
1.0 Structure	1614	kg
2.0 Protection	1006	kg
3.0 Propulsion	0	kg
4.0 Power	4668	kg
5.0 Control	0	kg
6.0 Avionics	287	kg
7.0 Environment	3159	kg
8.0 Other	3375	kg
9.0 Growth (30%)	3748	kg
Dry Mass	17857	kg
10.0 Non-Cargo	0	kg
11.0 Cargo	4774	Kg
Inert Mass	22631	kg
12.0 Non-Propellant	8864	kg
13.0 Propellant	0	kg
Total Mass	31495	kg

# Ares V 51.00.48 - 1.5 Launch



<b>EDS Stage</b>	<b>4 day LEO loiter</b>
Propellants	LOX/LH2
Usable Propellant	557,878 lbm (253.0 t)
Propellant Offload	0.0 %
Stage liftoff pmf	0.8828
Launch Dry Mass	52,912 lbm (24.0 t)
TLI Burnout Mass	58,194 lbm (26.4 t)
Suborbital Burn Propellant	330,000 lbm (149.7 t)
Pre-TLI Jettison Mass	7,344 lbm (3.3 t)
LEO FPR	8,553 lbm (3.9 t)
# Engines / Type	1 / J-2X
Engine Thrust (100%)	294,000 lbf / 238,000 lbf @ Vac
Engine Isp (100%)	448.0 sec / 449.0 sec @ Vac
Mission Power Level	100.0 % / 81.0 %
Suborbital Burn Time	502.9 sec
TLI Burn Time	429.9 sec

<b>Delivery Orbit</b>	<b>1.5 Launch TLI</b>
LEO Delivery	130nmi (240.8km) circ@29.0
TLI Payload from 100 nmi	156,832 lbm (71.1 t)
CEV Mass	44,500 lbm (20.2 t)
LSAM Mass	112,332 lbm (51.0 t)
Insertion Altitude	131.5 nmi (243.5 km)
T/W @ Liftoff + 1 sec	1.36
Max Dynamic Pressure	675 psf
Max g's Ascent Burn	4.17 g
T/W @ SRB Separation	1.46
T/W Second Stage	0.40
T/W @ TLI Ignition	0.53



## Vehicle Concept Characteristics

<b>GLOW</b>	<b>8,156,803 lbf (3700 t)</b>
Payload Envelope L x D	25.3 ft (7.7 m) x 30.0 ft (9.1 m)
Shroud Jettison Mass	19,953 lbm (9.1 t)

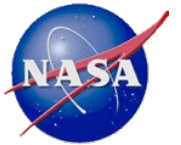
<b>Booster (each)</b>	
Propellants	PBAN (ATK-333-07 Trace)
Overboard Propellant	1,510,421 lbm (685.1 t)
Stage pmf	0.8656
Burnout Mass	234,514 lbm (106.4 t)
# Boosters / Type	2 / 5.5 Segment SRM
Booster Thrust (@ 1.0 secs)	3,744,000 lbf @ Vac
Booster Isp (@ 1.0 secs)	275.7 sec @ Vac
Burn Time	116.4 sec

<b>Core Stage</b>	
Propellants	LOX/LH2
Usable Propellant	3,499,458 lbm (1587.3 t)
Propellant Offload	0.0 %
Stage pmf	0.9014
Dry Mass	346,978 lbm (157.4 t)
Burnout Mass	382,958 lbm (173.7 t)
# Engines / Type	6 / RS-68
Engine Thrust (108%)	702,055 lbf @ SL    797,000 lbf @ Vac
Engine Isp (108%)	364.9 sec @ SL    414.2 sec @ Vac
Mission Power Level	108.0 %
Core Burn Time	303.1 sec

<b>Interstage</b>	Core/EDS
Dry Mass	20,264 lbm (9.2 t)

LV 51.00.48

# Ares IV for Direct Flexible Path Missions

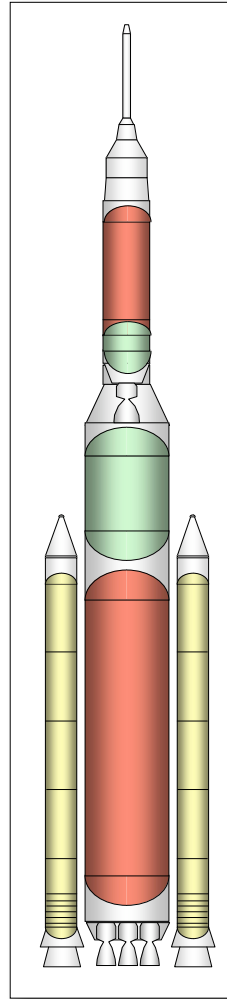


## ◆ Ares IV

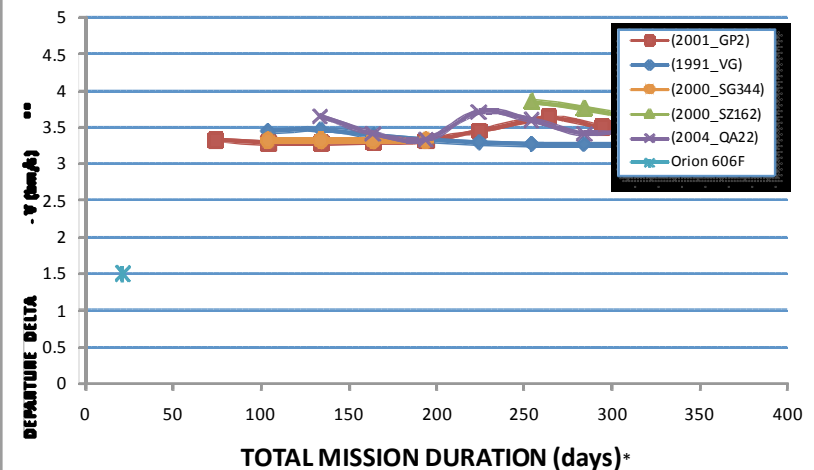
- Configuration LV 67.06.01
- 2 x 5 segment SRMs
- 5 x RS-68 Core Engines
- Ares I Upper Stage (J-2X)
- Short LEO Loiter
- 67.7 t useable propellant post-launch (no propellant conditioning)

## ◆ Performance Results

- Can push Orion 606F through 4,100 m/s (excess performance)
- Can inject 37 t toward “easier” NEOs

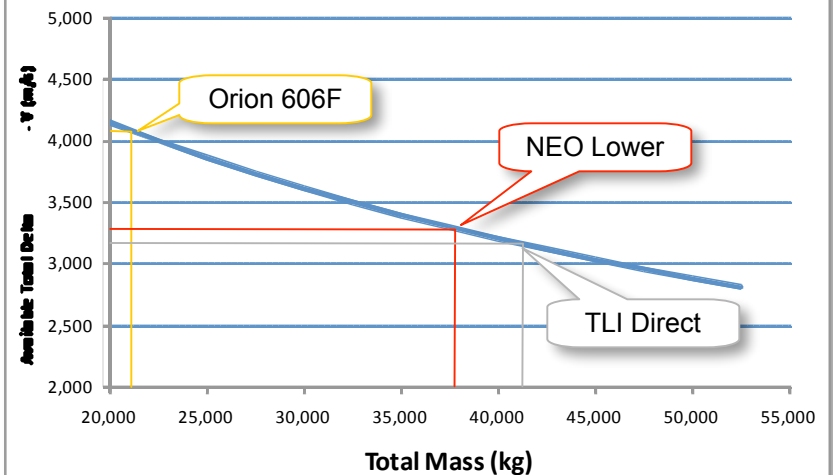


**EXAMPLE NEO MISSION OPPORTUNITIES**  
Departure Delta-v vs. Mission Duration



\* Total mission duration includes 14-day NEO target stay

**Ares IV Upper Stage Performance**  
Approximate Total Delta-V Available\* vs Payload Mass



\* Total available computed with EDS propellant load of 66,700 kg

LV 67.06.01

# EELV and Centaur upper stage Capability



## ATLAS V 500 SERIES



The Atlas V 500 series launch vehicle extends the capability of the Atlas V with the addition of a 5-meter diameter (4.57-meter usable diameter) payload fairing (with three length options) and solid rocket boosters. A dual-engine Centaur configuration provides additional performance capabilities for low to intermediate orbits. Performance of the 500 series vehicles can be tailored by incorporating up to five solid rocket boosters.

### Characteristics

Total liftoff mass: 333,298 kg (734,800 lbm)

Total length: 59.7 m (195.9 ft) with short Conquest payload fairing

	Atlas	Centaur
Length	32.46 m (106.5 ft)	12.68 m (41.6 ft)
Diameter	3.81 m (12.5 ft)	3.05 m (10 ft)
Propulsion	One RD-180 (two chambers)	One or Two RL10A-4-2
Thrust	1.82 MN (860 klb) - 100% SL	99.2 kN (SEC)* 198.4 kN (DEC)
Inert Mass	21,173 kg (46,678 lb)	1,914 kg (4,220 lb) (SEC) 2,106 kg (4,693 lb) (DEC)
Propellant Mass	284,089 kg (626,309 lb)	20,830 kg (45,920 lb)

\*Single Engine Centaur = SEC Dual Engine Centaur = DEC

The solid rocket boosters each have a fueled mass of approximately 44,000 kg (97,000 lb) and develop a thrust in excess of 1.36 MN (306,173 lb).

# Deep Space Airlock

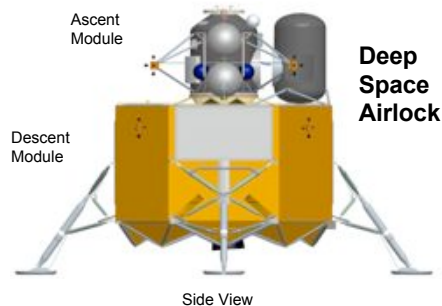


## **Deep Space Airlock**

Pressurized Volume:  $7.5 \text{ m}^3$   
Diameter: 1.75 m Height: 3.58 m  
Mass (at TLI): 1001 kg  
Crew Size: 2+

## Deep Space Airlock Concept

- Derived from the Lunar Lander concept airlock (p0810)
- Modified with additional radiation protection



p0810-A Lunar Lander