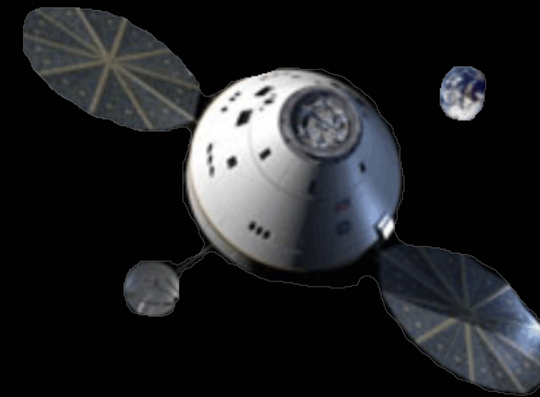
ORION/MOONRISE:
JOINT HUMAN-ROBOTIC
LUNAR SAMPLE RETURN MISSION CONCEPT



Leon Alkalai, Ben Solish, John Elliott,
Tim McElrath, Juergen Mueller, Jeff Parker
Jet Propulsion Laboratory,
California Institute of Technology

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Thank you

- Co-authors of this paper
- John Baker and Gary Burdick, JPL Human Exploration Program Office
- Brad Jolliff and Chip Shearer
- To the LEAG community for your attention

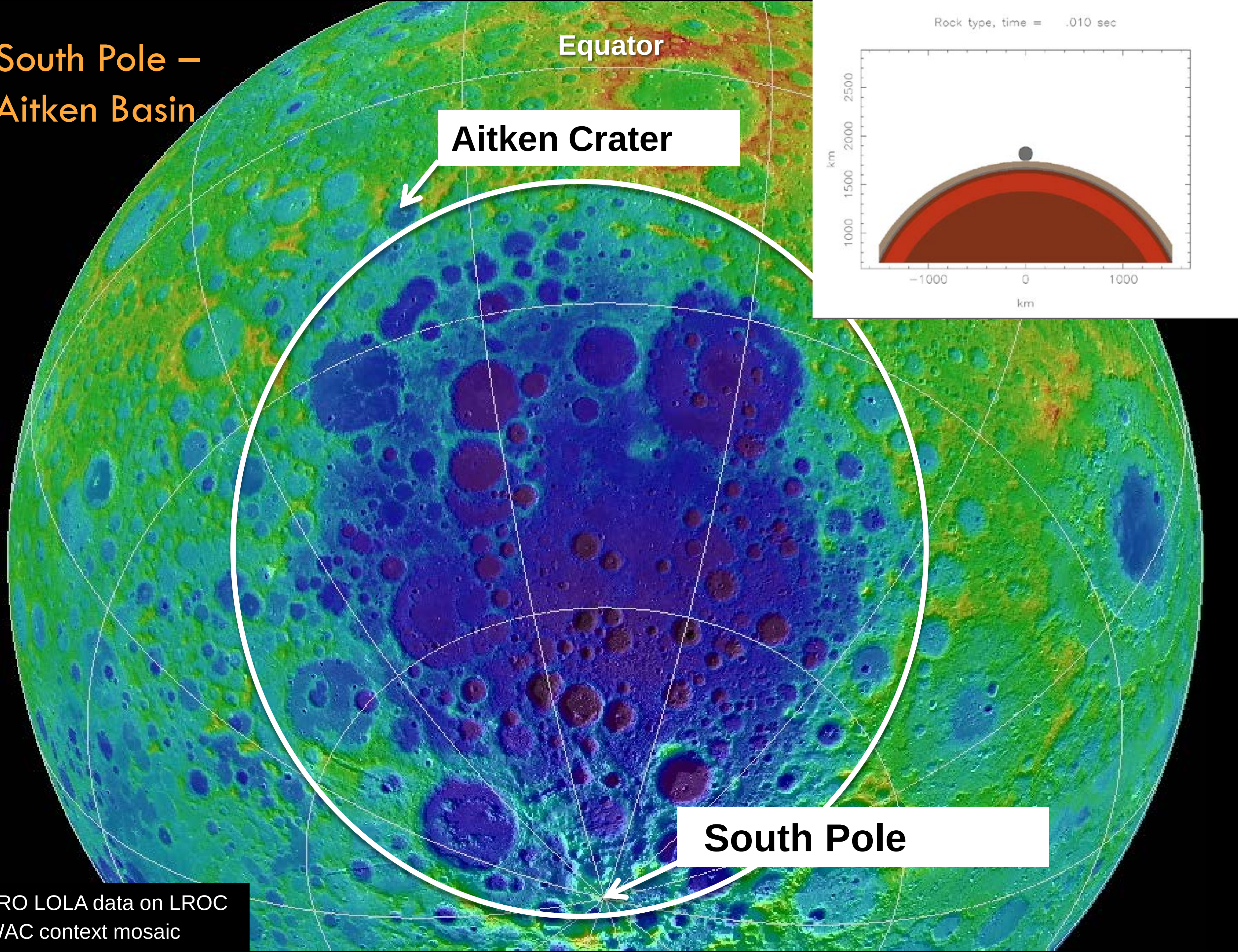
Orion/MoonRise Mission Concept:
Introduction & Motivation

- An opportunity for significant collaboration between SMD and HEOMD.

- Conduct an exciting and bold joint human-robotic mission in cis-Lunar space as a precursor to future Mars exploration by combining the mature MoonRise lander design with the HEOMD architecture.

- Accomplish high national priority Decadal Survey Science with the first sample return from the lunar farside; the key to understanding the formation of our Solar System and early evolution of the Earth-Moon System at a time when life originated on Earth.

South Pole – Aitken Basin



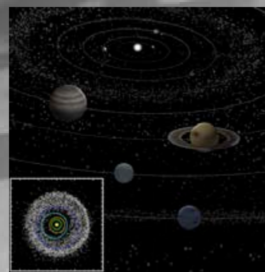
LRO LOLA data on LROC WAC context mosaic

MoonRise sample return addresses key Solar System Science as endorsed by the NRC!

Addresses key objectives for Planetary Science.

Advances scientific knowledge of Solar System history and processes.

Impact Cataclysm

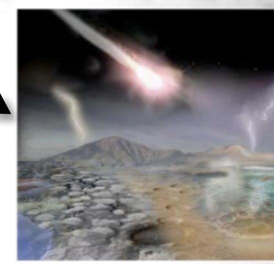


Dynamics of the Outer Solar System

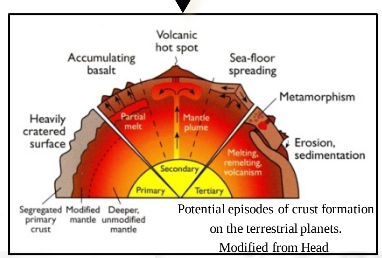
Effects of Giant Impacts on Planetary Evolution

How the Solar System evolved to its current, diverse state.

Origin of the Earth-Moon system



Planetary Environments for the Origin and Evolution of Life



Potential episodes of crust formation on the terrestrial planets. Modified from Head

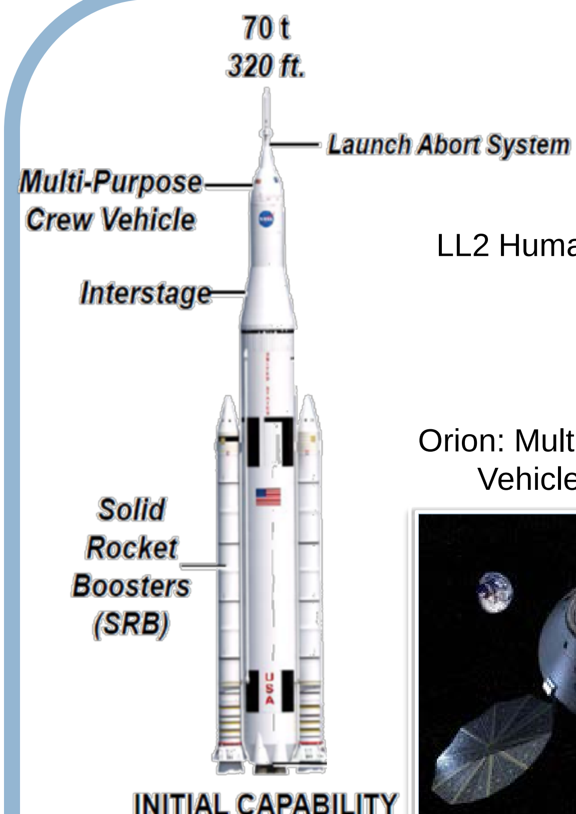
Differentiation and Thermal History of the Terrestrial Planets

Implications for the history of Earth at a critical time in the development of its habitable environments and the origin and survival of Earth's early life.

Orion/MoonRise:

Architectural Elements of the Study

Human Architectural Elements



LL2 Human Habitat Station (JSC)

Orion: Multi Purpose Crew Vehicle (JSC, LM)

SLS: Space Launch System (JSC, MSFC, KSC)

Robotic Architectural Elements

MoonRise New Frontiers Phase A Study (JPL, LM)

ALHAT: Autonomous Landing and Hazard Avoidance Technology (JSC, LaRC, JPL, APL, GRC)

Axel: Scalable low mass tethered rover for very steep terrain access & sample collection (JPL)

Orion/MoonRise: Human/robotic sample return from the South Pole - Aitken Basin

Planning and discussion Purposes Only

- Orion & MoonRise
  - Launch together
    - Cruise together (Apollo-like. Moonrise docked with CEV, delivered to drop)
    - Cruise separately (Moonrise launches as 2ndry PL on SLS)
  - Launch separately (Moonrise launches on EELV prior to crew)

- Orion in LLO
- Orion in ELO
- Orion at EM-L2

- MR parks in EM-L2
- MR parks in EM-L1
- MR parks in LLO
- MR parks in ELO

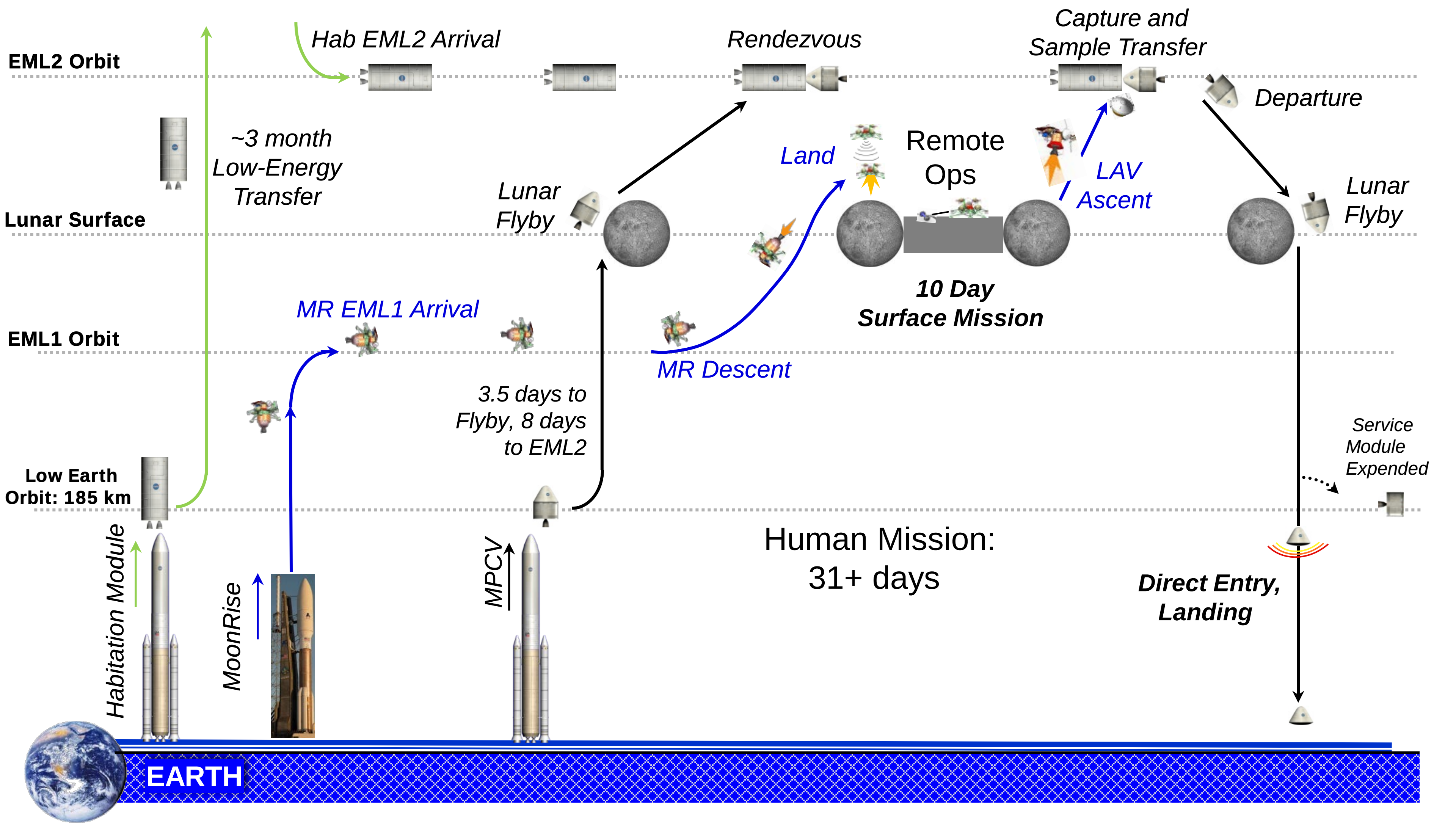
- Autonomous Surface Ops
  Orion serves comsat function only
- Teleoperations from Orion
  - Mobility
    - ATHLETE mobility
    - AXEL rover
      Demo and extended sample collection

- Sample return to Earth
  CEV enhances surface ops only
- Sample return to Orion

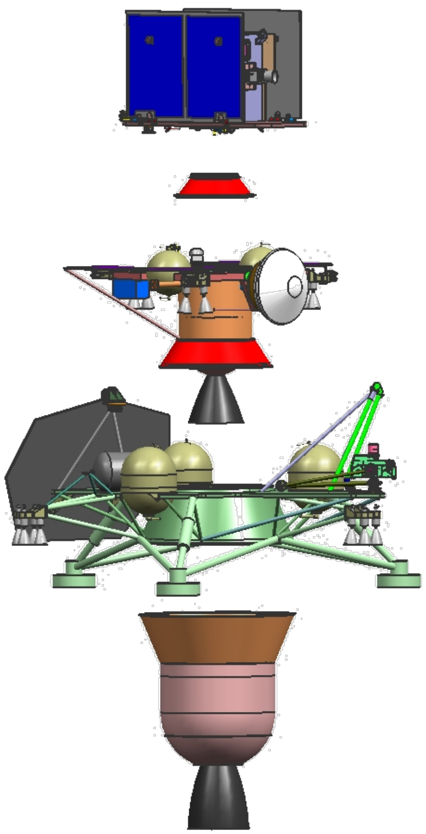
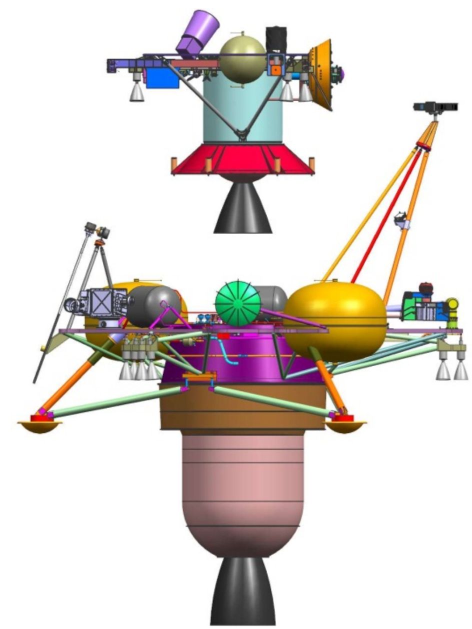
Orion/MoonRise:
Mission Concept Outline:

- Assume human habitat module is launched on SLS and is established at or around EM-L2.
- The MoonRise robotic sample return vehicle (SRV) is launched.
- After the SRV has successfully arrived at its staging orbit (EM-L1 or EM-L2), Orion is launched with astronauts to EM-L2 using the crew version of SLS.
- Once Orion is ready at EM-L2, the SRV lander lands at the South Pole-Aitken Basin with Orion providing relay critical coverage during descent.
- Upon landing, the lander, tele-operated by astronauts from Orion, uses advanced robotics and mobility systems to sample and retrieve precious scientific samples and store them in a container in the Lunar Ascent Vehicle.
- The Ascent Vehicle with as much as **10 - 30 kg** of samples ascends to EM-L2 station.
- Astronauts in Orion capture sample canister at EM-L2 and return samples back to Earth.
- This mission demonstrates human/robotic sample return for future Mars missions and brings high science value payload to the science community.
- Excellent opportunity for public engagement and outreach!

Orion/MoonRise Mission Architecture



Orion/MoonRise:
Small updates to the MoonRise 2010 Architecture

MoonRise 2010	Implementation Approach	Orion/MoonRise Lander
	**<u>Com Sat</u>** **<u>LAV & SRC</u>** **<u>LSM</u>** **<u>LBM</u>**	Orion  

Orion/MoonRise: modified SRV

2x ATK/PSI 80512 Tanks

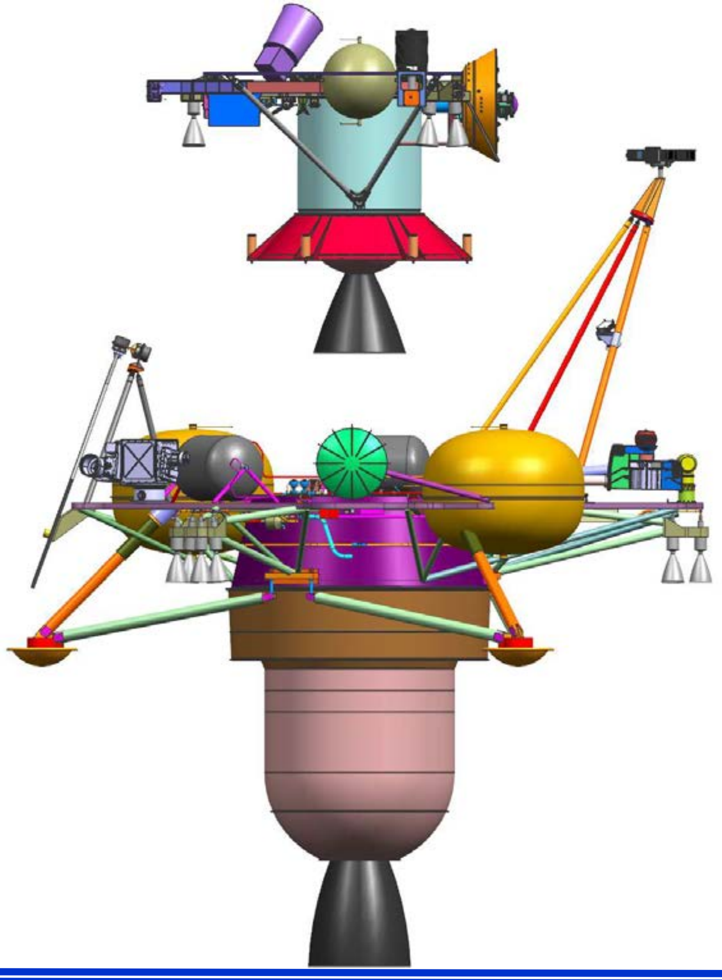
49 kg N_2H_4

Off-the-shelf

STAR 30 C/BP

Fully loaded

Off-the-shelf

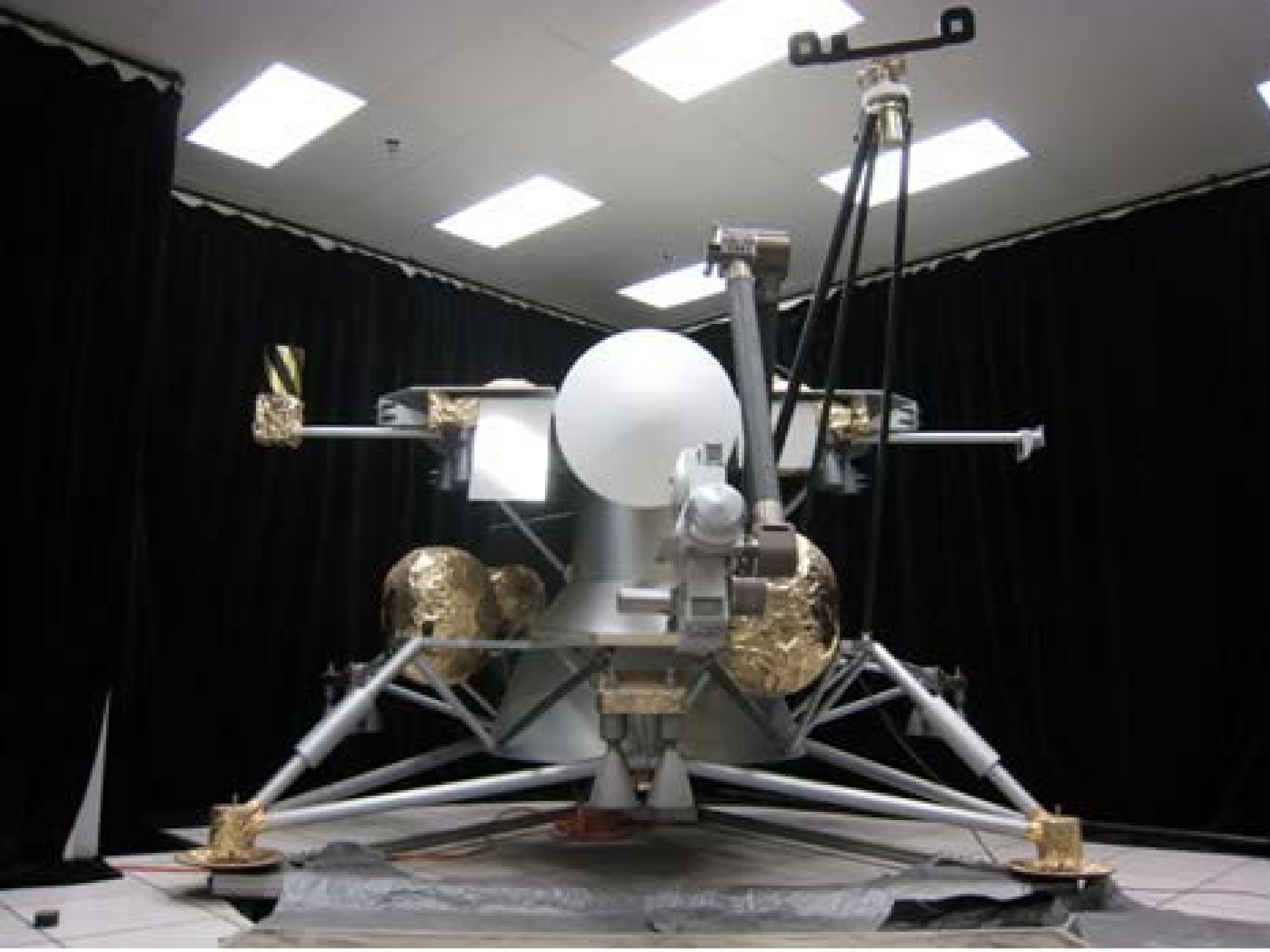


2x ATK/PSI 80407 Tanks

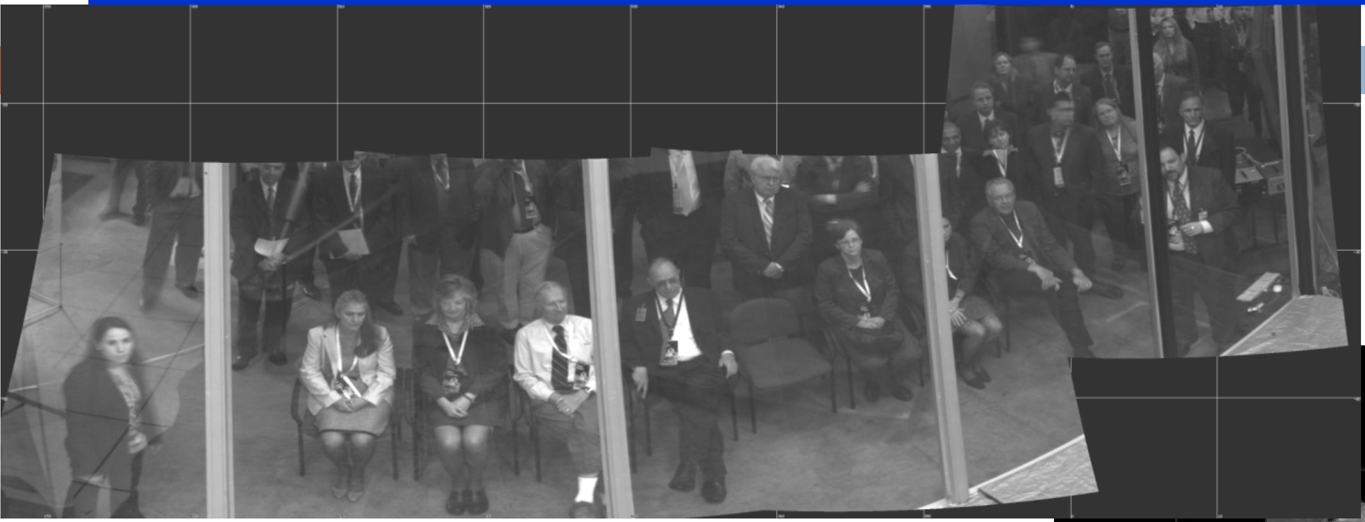
462 kg N_2H_4

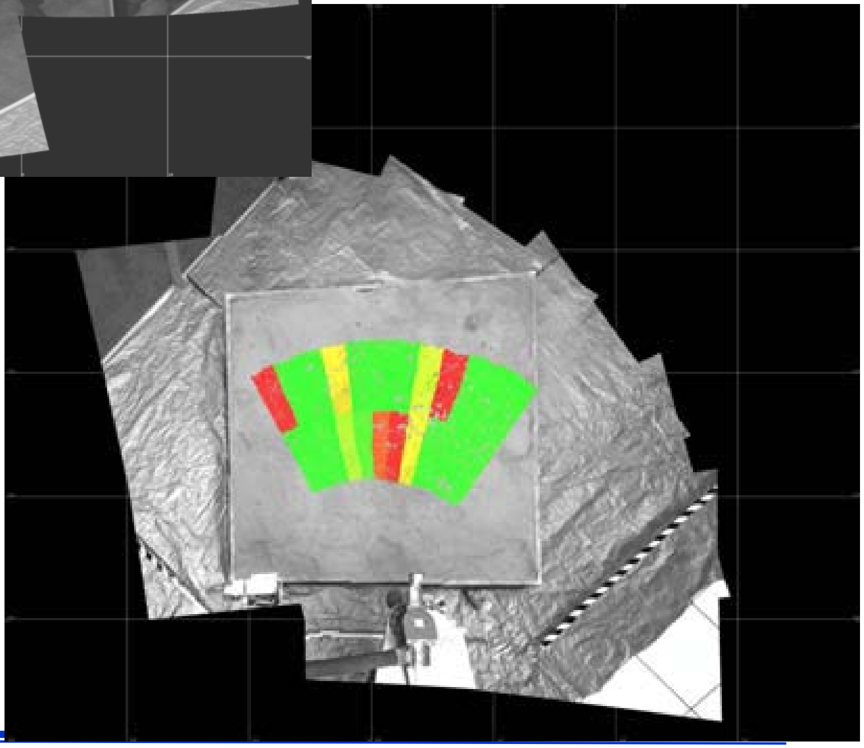
Off-the-shelf

STAR 48AX 7.5% uploaded vs MoonRise 2010

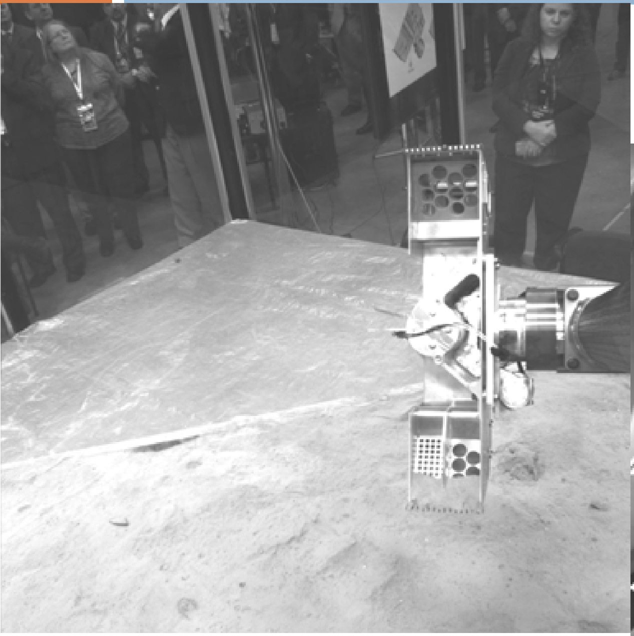


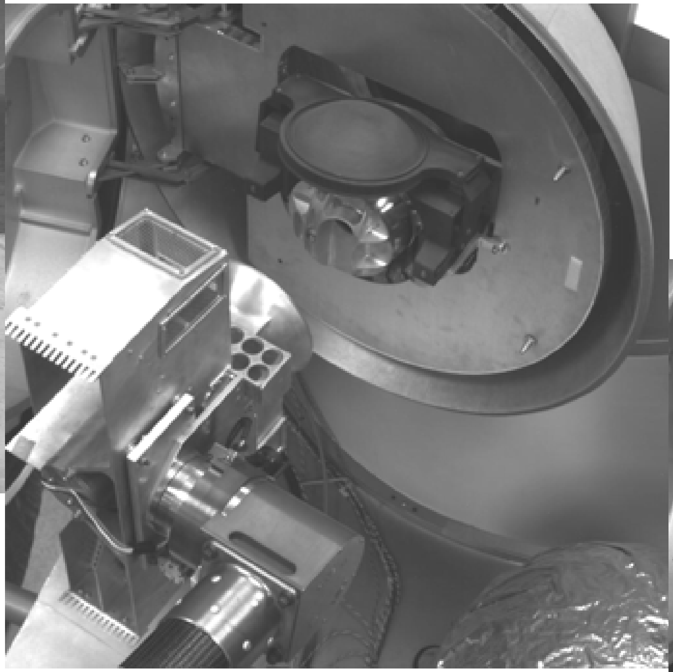
MoonRise Lander: Workspace characterization

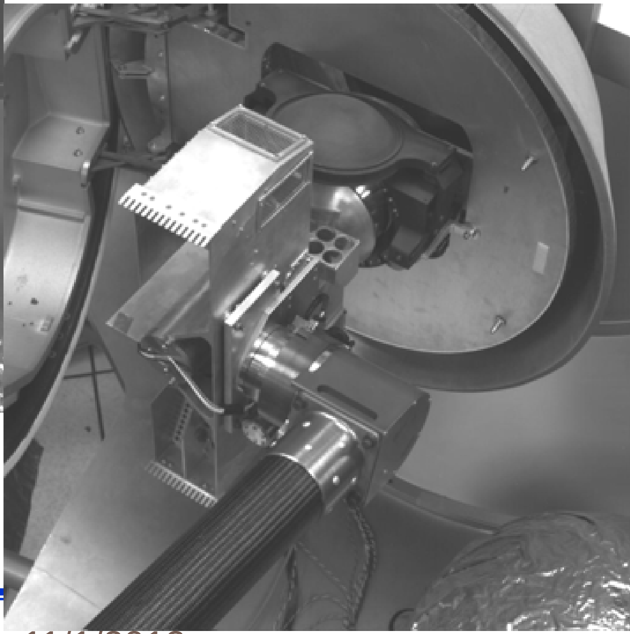




MoonRise Lander:
Sample Acquisition and Transfer System







Orion/MoonRise Mission Design:
SRV Staging at EM-L1, Ascent to EM-L2

Scenario

- Launch well before humans; take a low-energy transfer to the Moon; pass through the EM-L2 vicinity and arrive at a halo orbit about EM-L1.
- Remain at EM-L1 until humans launch; then proceed with descent to surface.
- Land via shallow flight path angle; remain on the surface for up to 10 days.
- Ascend via a high flight path angle on a direct return path to the EM-L2 orbits where humans will be stationed.
- Humans then rendezvous and pick up samples at EM-L2 for return to Earth.

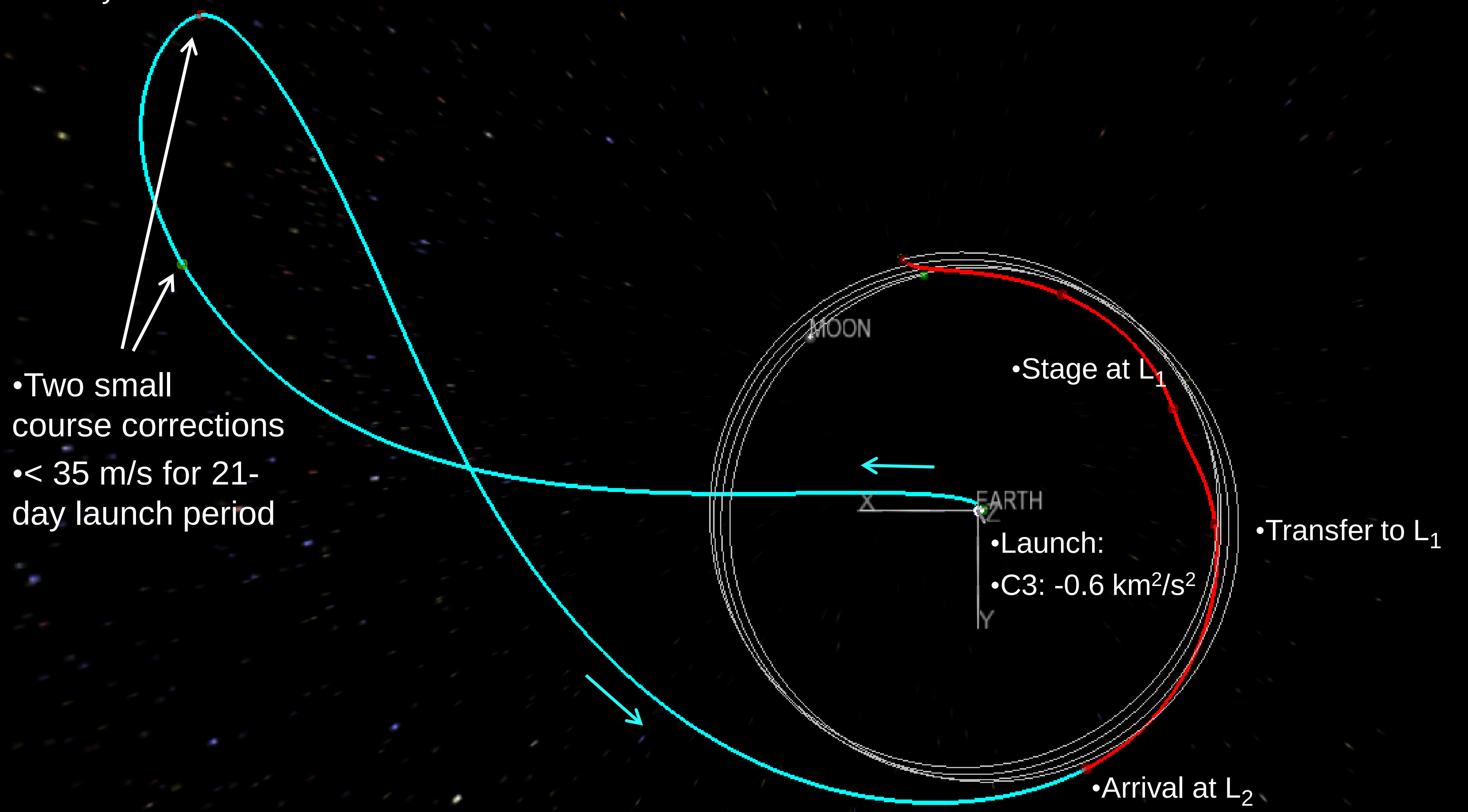
Comments

- This option is almost identical to the MoonRise New Frontiers Proposal.

SAMPLE RETURN VEHICLE: LAUNCH, TLC

- Human MoonRise Mission
- Sun-Earth Rotating Frame
- Viewed from Above

- 3 month low-energy transfer to the Moon
- Staging at L_1 or L_2
- 7.5 day descent, which may begin before humans arrive at L_2
- 10.6 days on the surface
- 4.5 day ascent from surface to halo



- Human MoonRise Mission
- Earth-Moon Rotating Frame
- Viewed from Above

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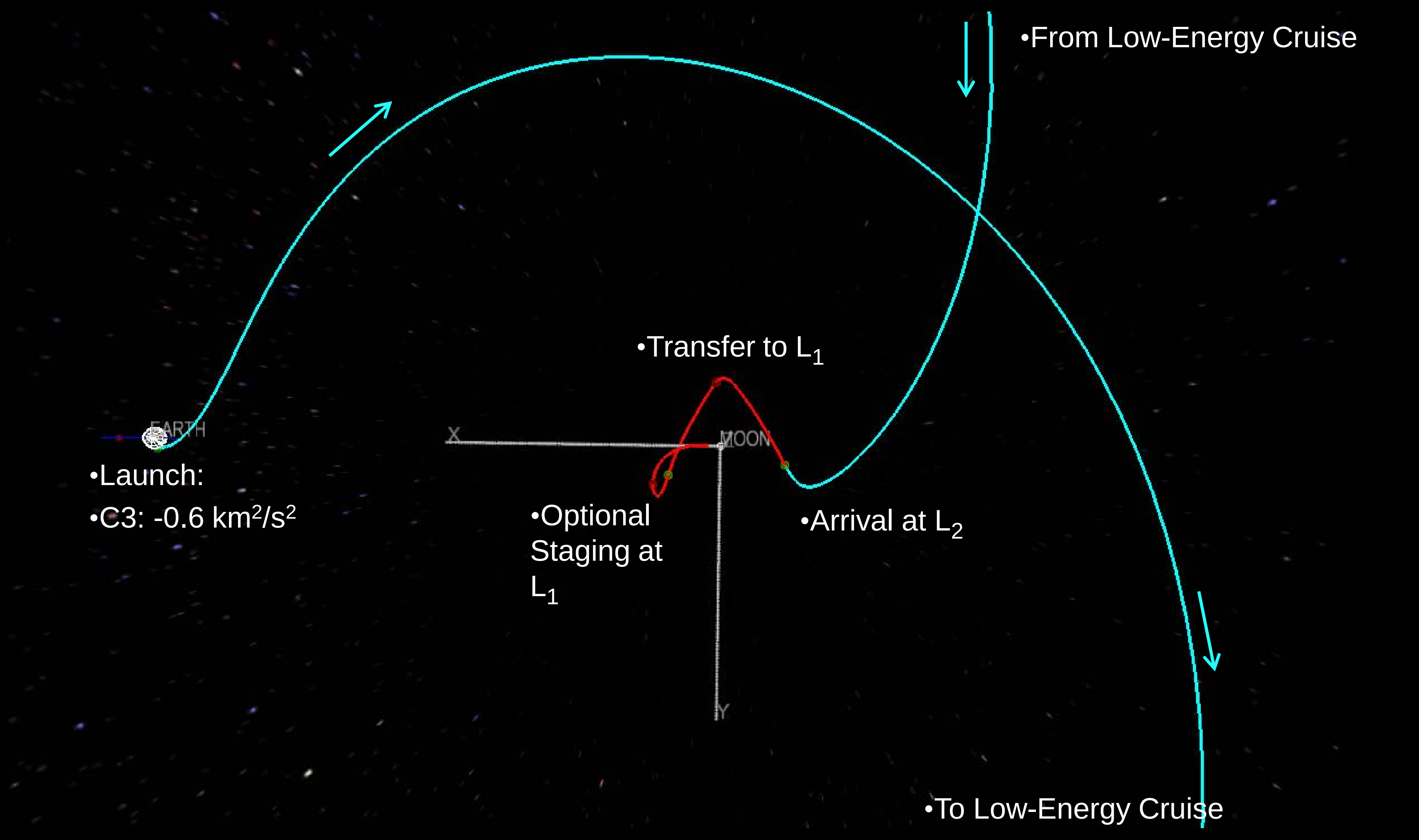

- Human MoonRise Mission
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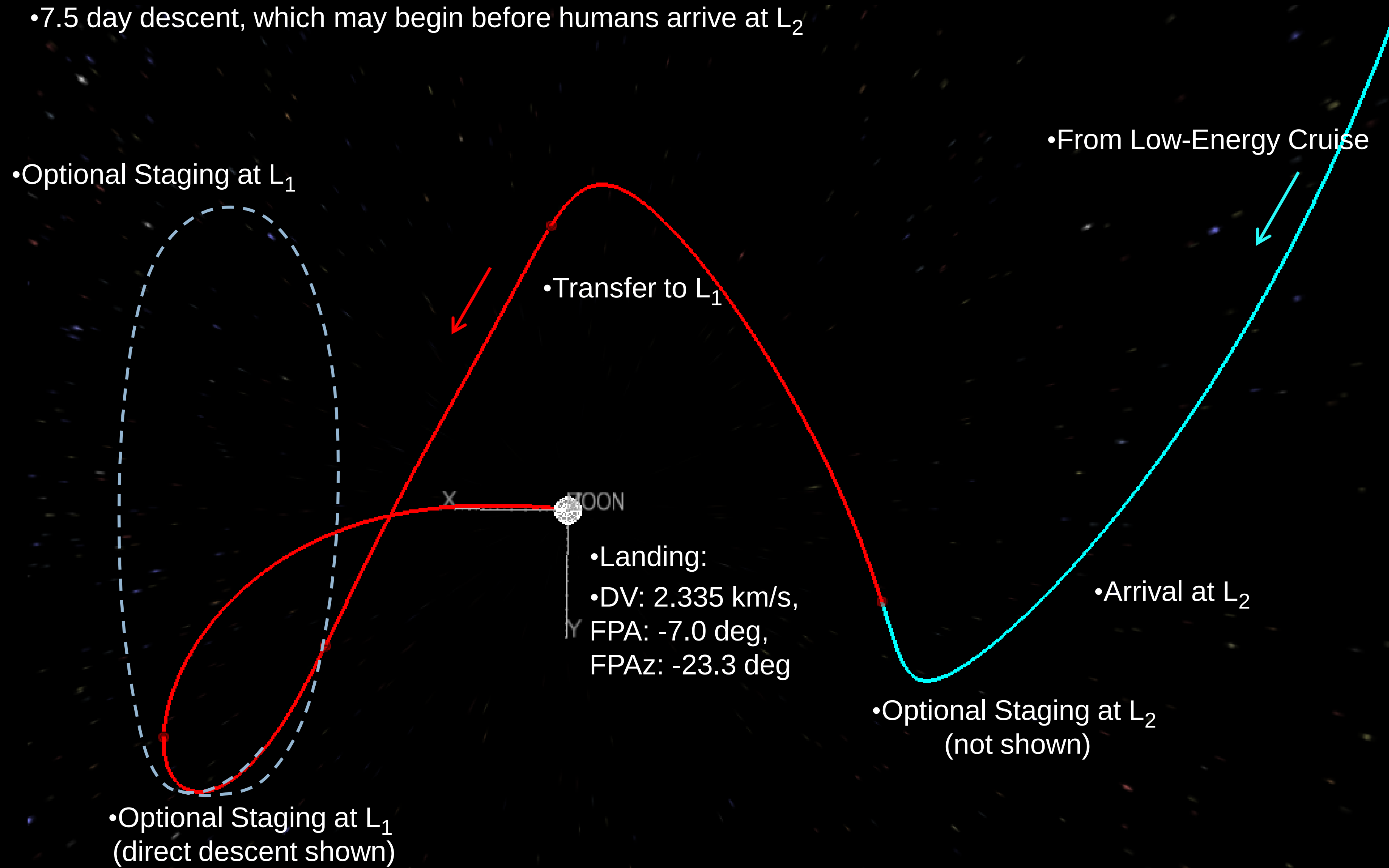
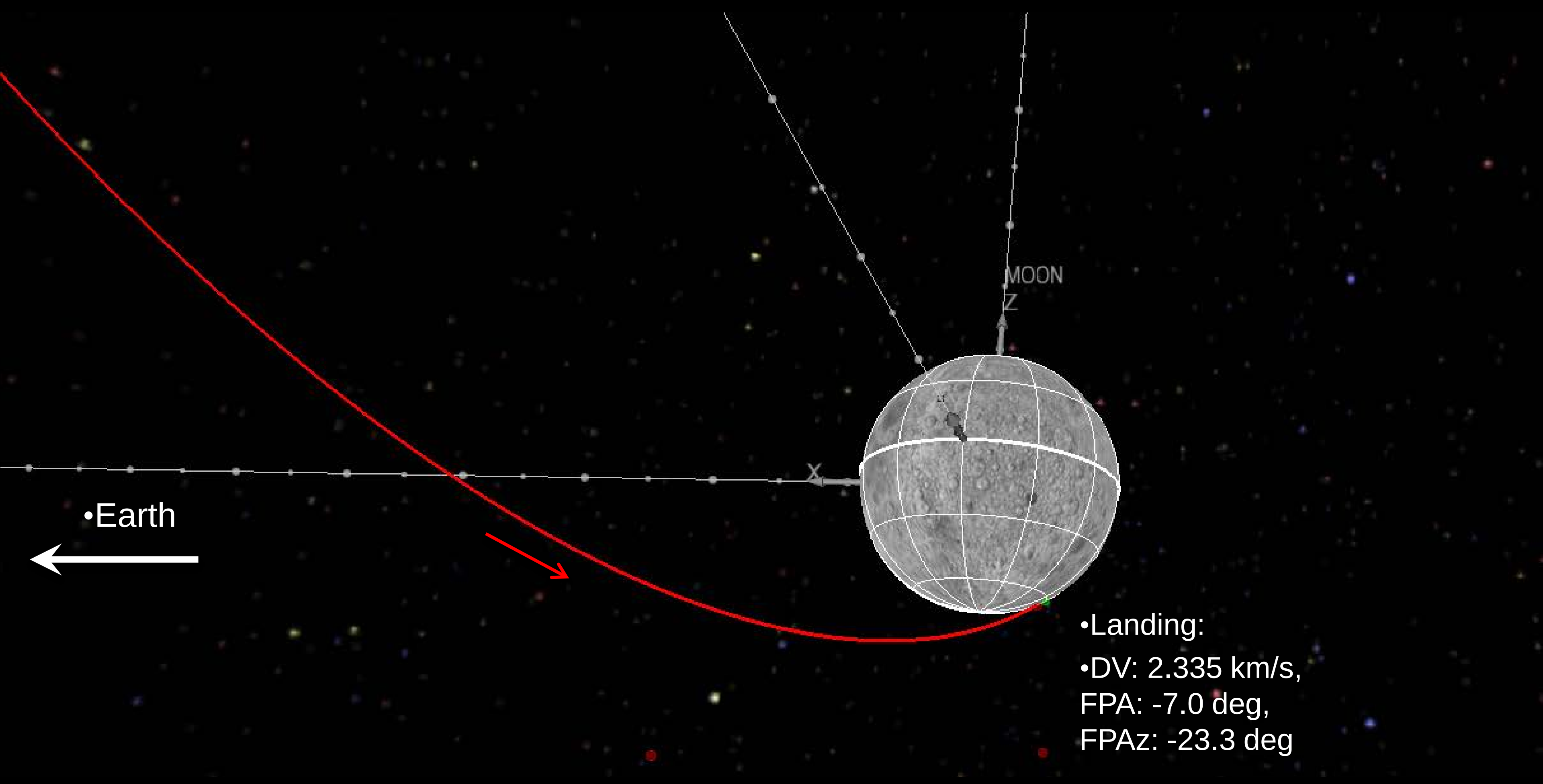


SAMPLE RETURN VEHICLE: DESCENT

•Human MoonRise Mission

•Moon-centered
Viewed from the Side

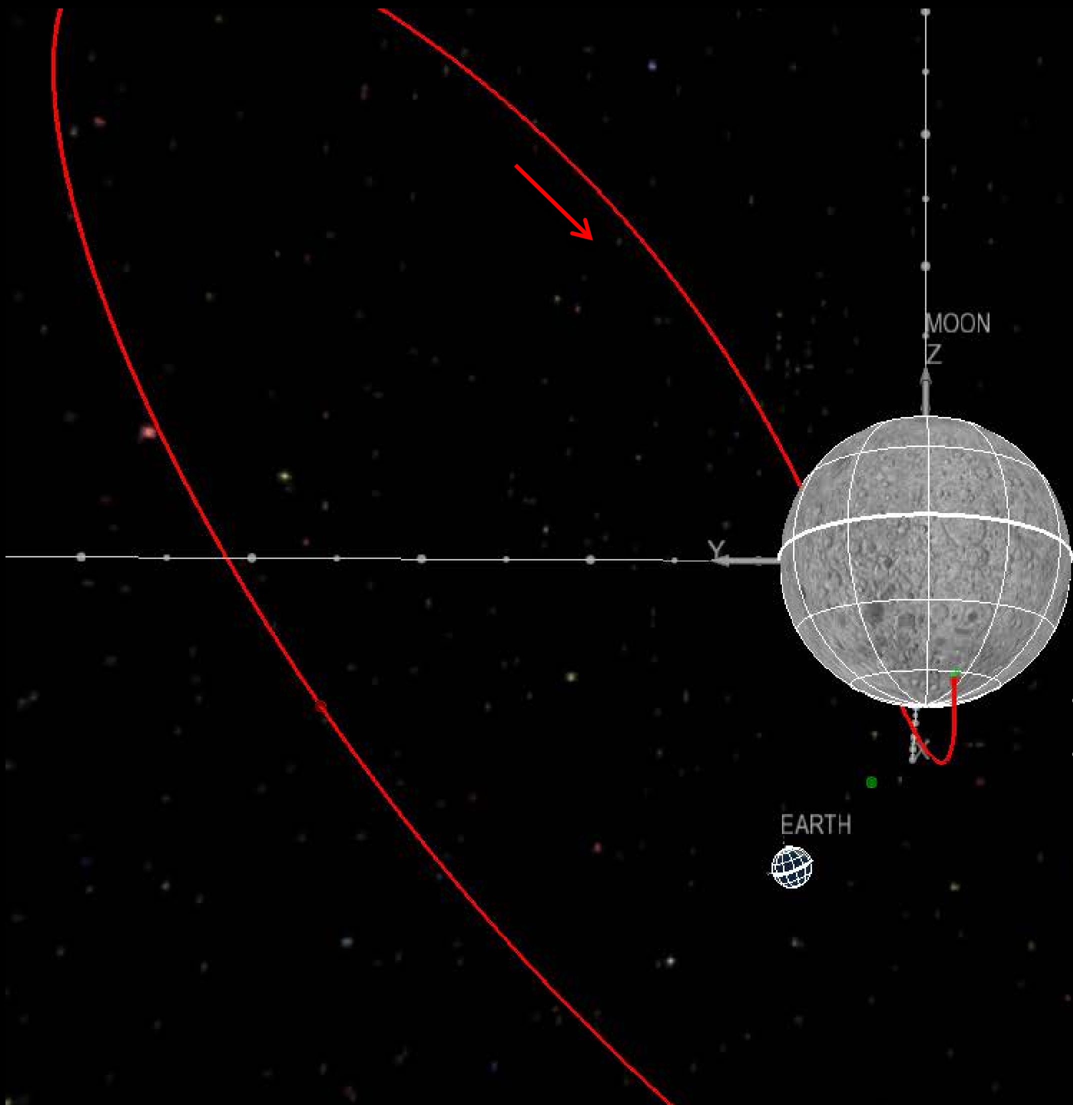
•3 month low-energy transfer to the Moon
•Staging at L_1 or L_2
•7.5 day descent, which may begin before humans arrive at L_2



•Human MoonRise Mission

•Moon-centered
Viewed from the Back

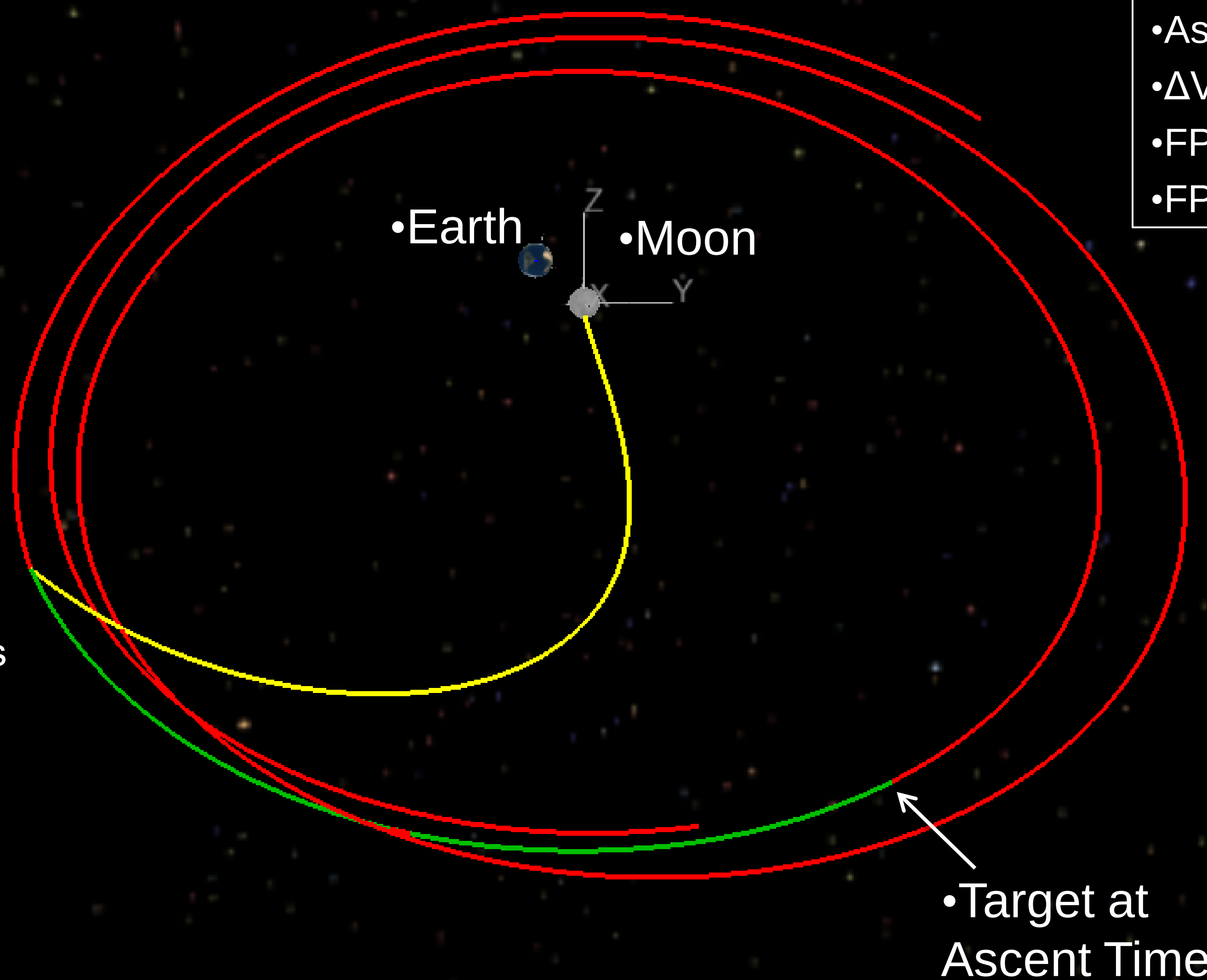
•3 month low-energy transfer to the Moon
•Staging at L_1 or L_2
•7.5 day descent, which may begin before humans arrive at L_2



•Landing:
•DV: 2.335 km/s,
FPA: -7.0 deg,
FPAz: -23.3 deg

LUNAR ASCENT VEHICLE: ASCENT

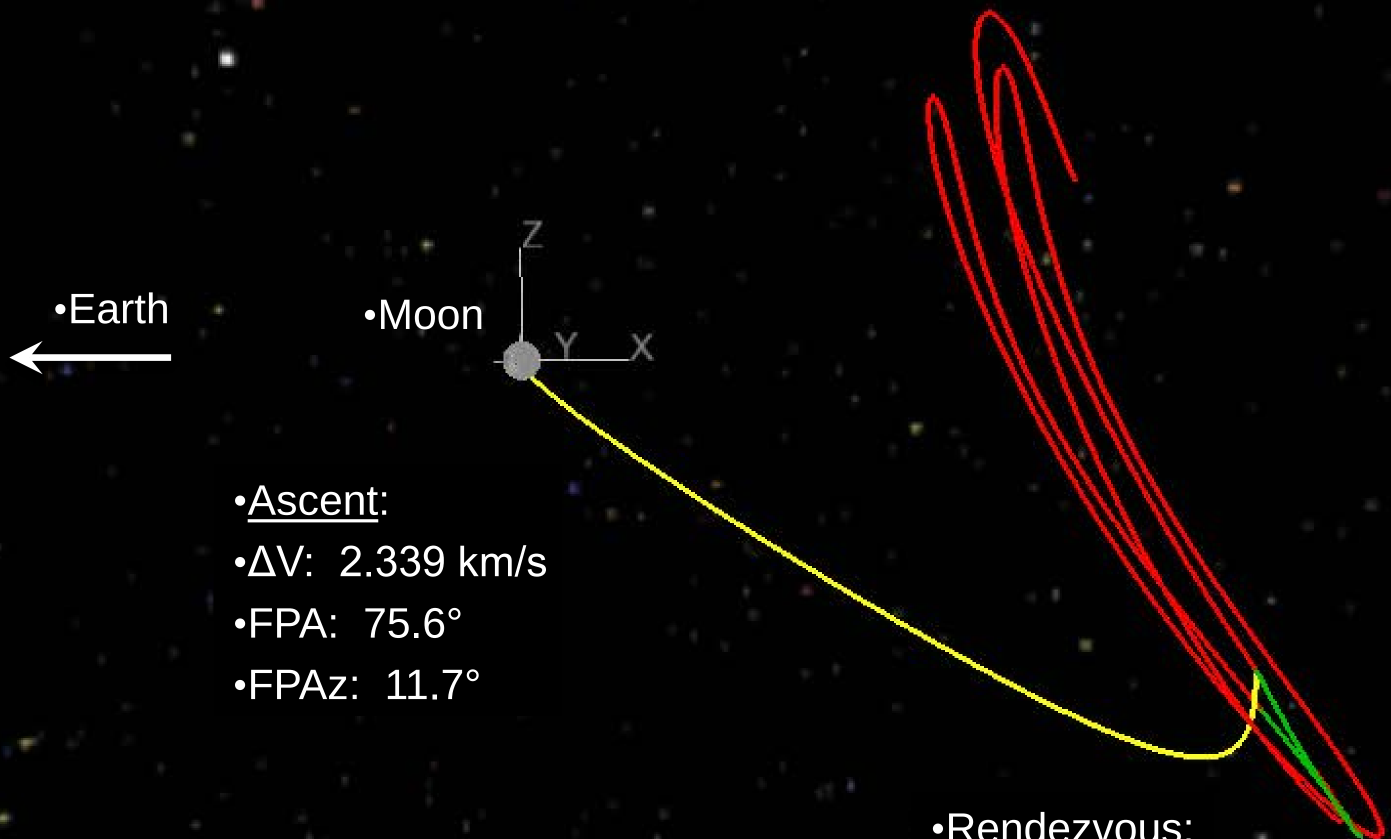
•View from Behind Halo



- •Ascent:
- •ΔV: 2.339 km/s
- •FPA: 75.6°
- •FPAz: 11.7°

- •Rendezvous:
- •ΔV: 70.9 m/s
- •ΔT: 4.5 days

- View from the Side



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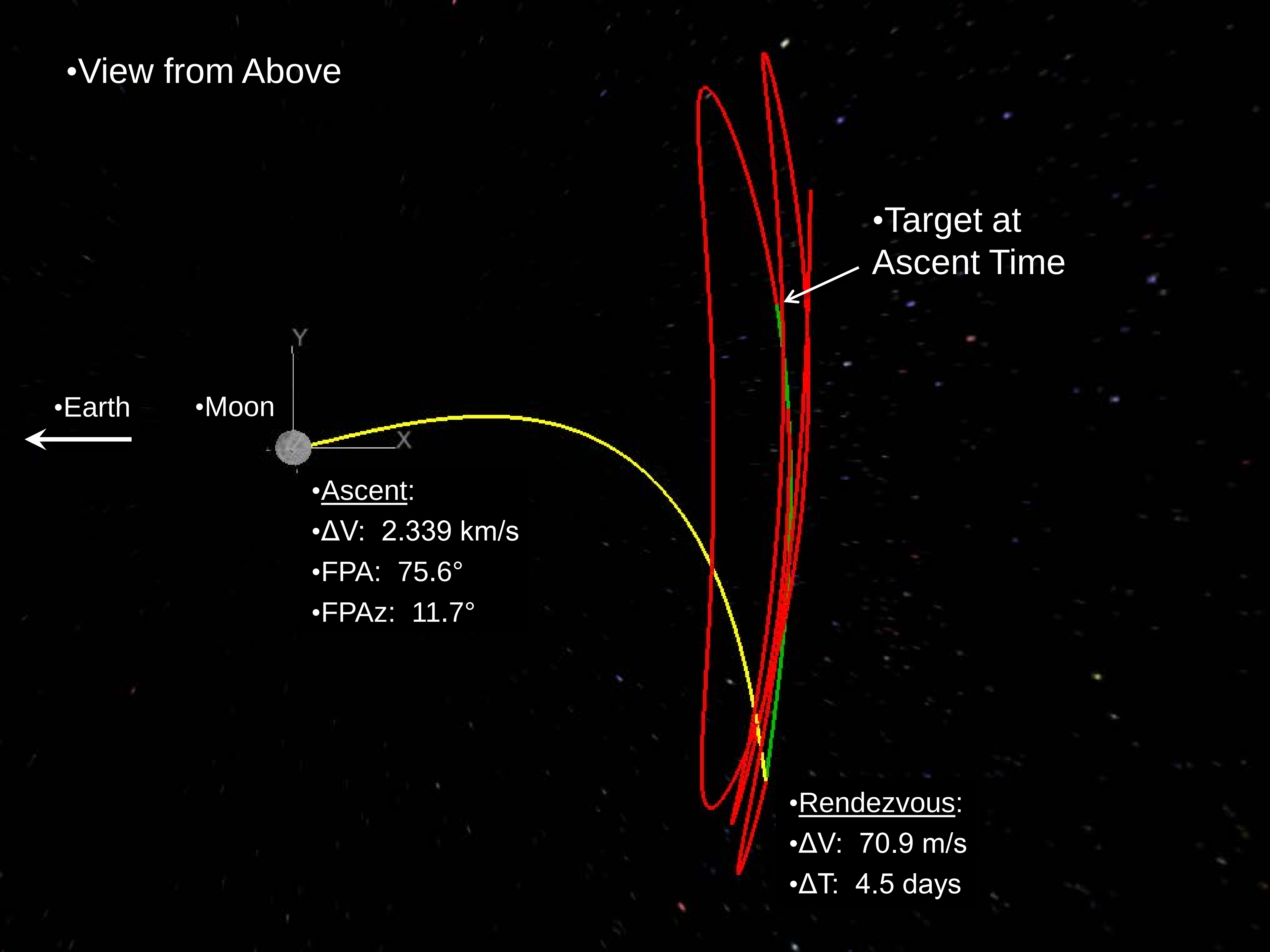
•View from Above
•Target at Ascent Time
Y
X
•Earth
•Moon
•Ascent:
•ΔV: 2.339 km/s
•FPA: 75.6°
•FPAz: 11.7°
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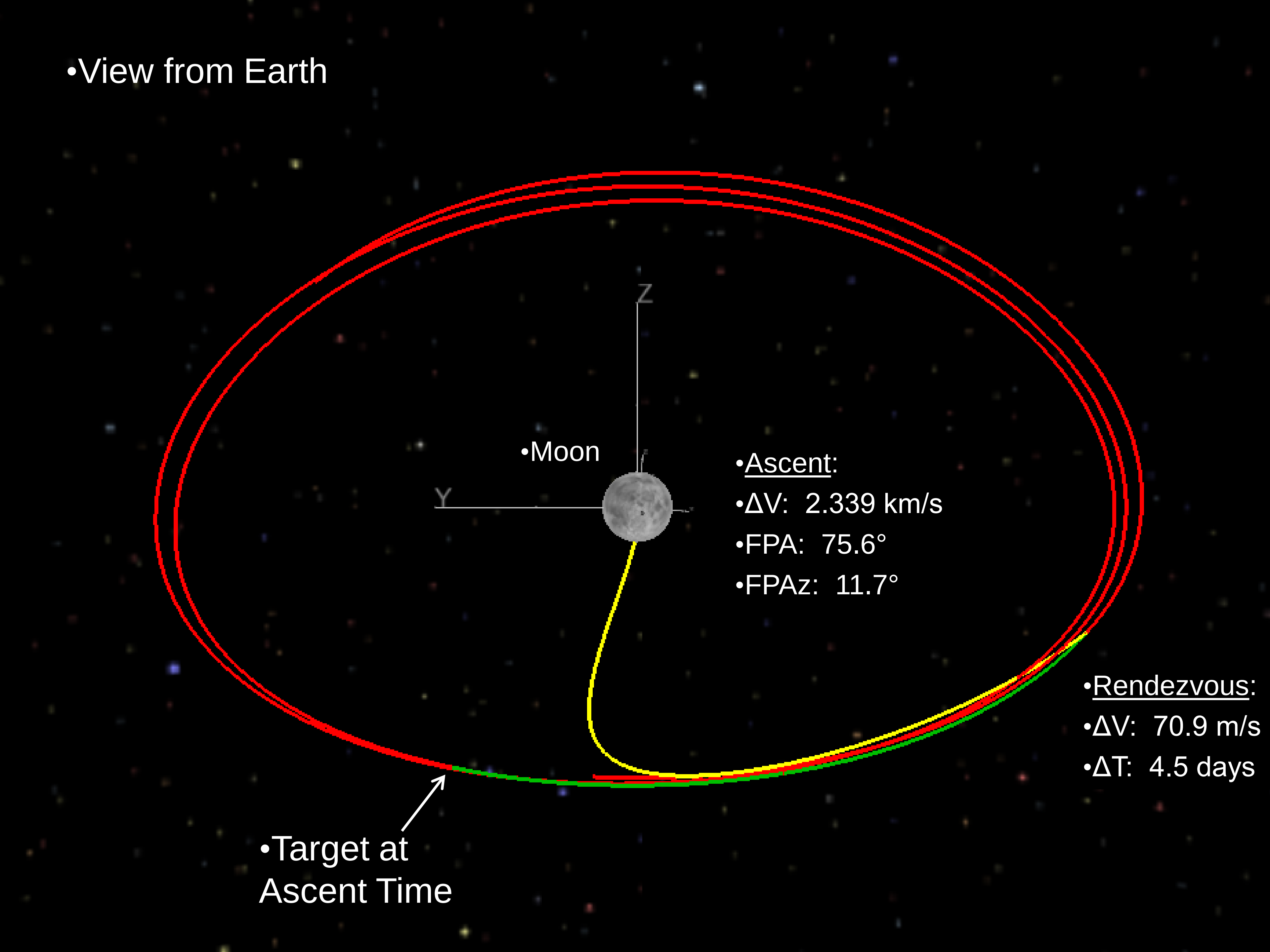
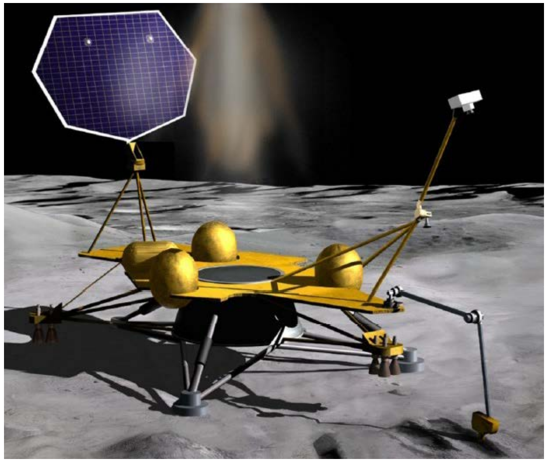

•View from Earth
•Moon
Z
Y
•Ascent:
•ΔV: 2.339 km/s
•FPA: 75.6°
•FPAz: 11.7°
•Rendezvous:
•ΔV: 70.9 m/s
•ΔT: 4.5 days
•Target at Ascent Time

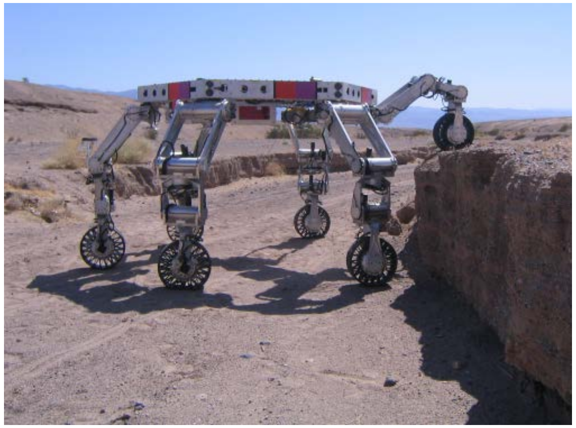
Orion/MoonRise delta-V:
Staging at EM-L1 (descent); Ascent to EM-L2

Mission Phase	Mission Element	ΔV (m/s)	Comments
Trans-Lunar Cruise			
	Deterministic ΔV	40	May be less, but it's good to carry a little extra here.
	Statistical	20	Added 12 m/s for a year of station keeping
	ACS	-	Propellant usage
	L1 Departure, Targeting	48	1-2 Additional maneuvers (not fully studied). This could be small (20?) or maybe even a little higher (50?), but probably around 30.
Landing			
	BB SRM + attitude control	2232.34	See MR Proposal
	Velocity Cleanup	167.64	
	Terminal Descent and Landing	172.48	
	Configuration Change	-	Leave lander, gain sample
Ascent			
	Pop-up	12.45	
	AB SRM + attitude control	2351	We have a smaller velocity target than MR, so this is probably conservative.
	Clean-up	63.5	
	Rendezvous	71	This may be smaller for longer-duration ascents, or larger for smaller-duration ascents.
	Statistical	28	Introduction of a rendezvous clean-up maneuver.
	ACS	-	Propellant usage
	Margin	50	I would recommend a large Margin since we haven't fully explored everything. 50 seems okay.

Orion/MoonRise Lander:
Mobility Asset & Sample collection

- The MoonRise arm provides a heritage design for the primary sample return
- AXEL rover is a scalable (20-50kg) tethered rover
- Tech demo that could provide samples from outside the landing zone
  - Pictures of the Lander and launch





Orion/MoonRise Mission: Science & Technical Return

Science Return

- Returning ~10-40 kg of samples
- Examine a unique record of the early solar system
- Analysis of the preserved rock fragments in the South Pole-Aitken basin
- Sample return from this area has consistently been a priority of the Decadal Survey

Technical Return

- Demonstration of human robotic sample return mission
- Demonstration of human robotic operations:
  - Feed forward to future Mars Missions
  - Critical relay coverage
  - Tele-robotics
- Demonstrates the flexibility of the EM-L2 as a destination, use of the Orion vehicle, surface assets
- Demonstration of Axel Mobility System

Public Engagement

- Pictures of Lander and launch from the surface of the Moon
- Exciting demonstration of human robotic exploration
- Sample capture at EM-L2
- First samples from another planetary body since the 1970s
- First ever samples from the SPAB

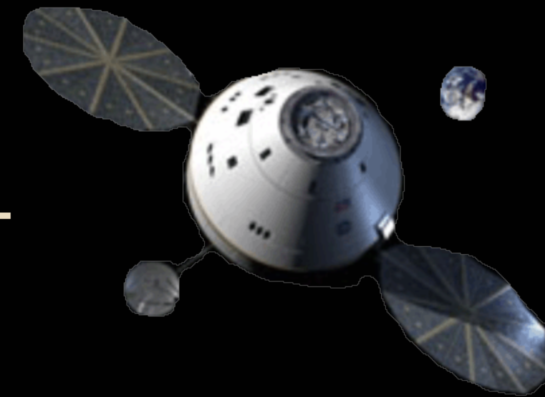
Orion/MoonRise: Conclusion

- There is an integrated architecture that allows us to draw on our knowledge of planetary landers to demonstrate planetary sample return and human robotic interaction around a planetary body.

- Combining the Science return from a MoonRise style mission with the human assets provides a clear opportunity for significant technical and scientific return.

- Orion/MoonRise mission concept provides clear feed-forward to Mars sample return and Mars human exploration.

ORION/MOONRISE: JOINT HUMAN-ROBOTIC LUNAR SAMPLE RETURN MISSION CONCEPT



Thank you for your attention.

Leon.Alkalai@jpl.nasa.gov

Executive Summary

- Using the MoonRise approach with minor design modifications, retrievable rock sample mass can be significantly increased from 1 kg to **38 kg, and a micro-rover be deployed** using the human way-point scenario at L2.
  - Lander mass will increase over MoonRise 2010 by approx. 400 -500 kg depending on landing scenario, yet launch injected mass is still lower than MoonRise 2010 by 200-300 kg due to elimination of comsat and comsat adapter.
  - If 1 kg and no rover deployment goal of MoonRise 2010 is maintained, Orion/MoonRise lander mass will decrease or increase slightly over MoonRise 2010 lander mass depending on landing scenario due to higher delta-v requirements, offset by lighter SRC mass for the LAM. Launch injected mass will drop by 600-700 kg over MoonRise 2010.
- Both Trans-L1 and L2-Direct mission scenarios are workable maintaining the MoonRise approach, with the L2-Direct landing scenario requiring higher terminal decent and landing delta-v resulting in higher S/C masses over the trans-L1 case by up to 100 kg depending on sample mass.
- The L2-orbit landing scenario requires too high a liquid delta-v for orbit insertion and cannot be accommodated using the MoonRise approach.
- Minor MoonRise design modifications are required to facilitate the Trans-L1 and L2-Direct landing scenarios:
  - Change from 3 MSL tanks on the LSM to 2 LCROSS tanks. Lower tank pressure rating reduces thruster feed pressure and Isp, taken into account. This affords approx. 50% propellant margin. Customized tank can reduce mass.
  - Stretch the MoonRise STAR 48AX design further by 7.4% (Trans-L1) and 12% (L2-Direct) to return 38 kg of lunar rock sample. Stretches can be reduced by reducing returned rock sample mass.
  - Use a fully loaded STAR 30 C/BP for ascent, rather than a 6% downloaded version for MoonRise to maximize rock sample return. A 1-kg sample return will allow for greater offload than for MoonRise 2010 due to lower SRC mass.