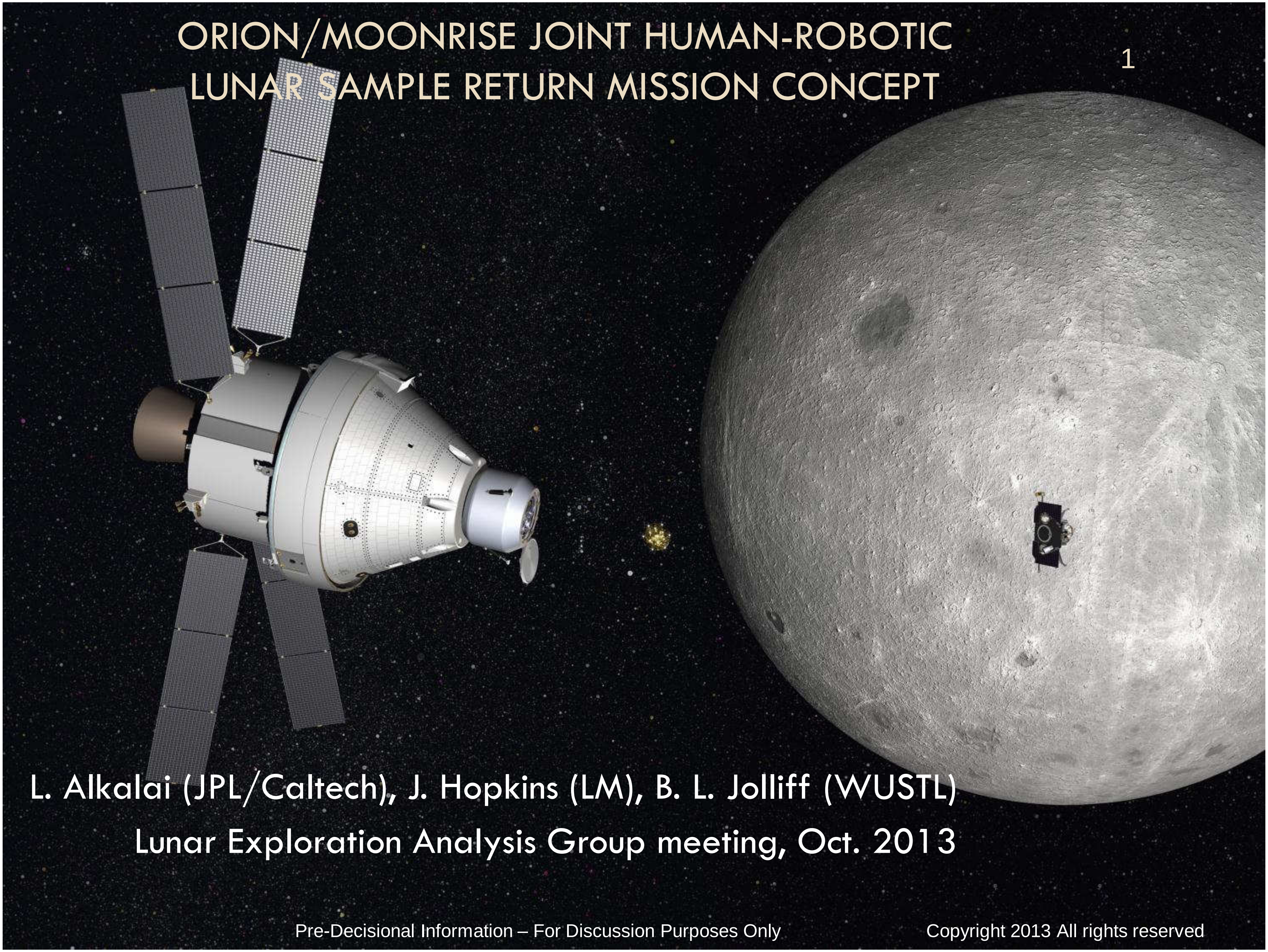
ORION/MOONRISE JOINT HUMAN-ROBOTIC LUNAR SAMPLE RETURN MISSION CONCEPT



L. Alkalai (JPL/Caltech), J. Hopkins (LM), B. L. Jolliff (WUSTL)

Lunar Exploration Analysis Group meeting, Oct. 2013

Acknowledgement

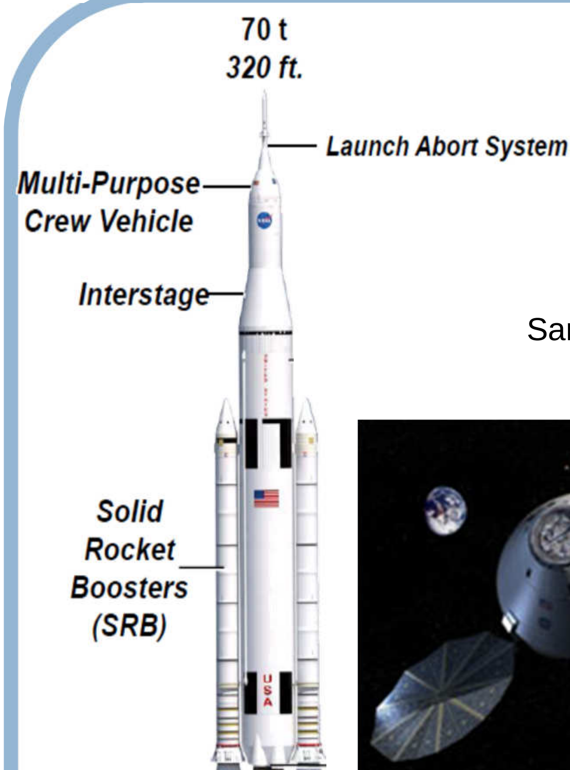
- Joint team effort at JPL/Caltech, LM and WUSTL
  - JPL/Caltech: L. Alkalai, Ben Solish, Tim McElrath, Juan Sennett, Ashitey Trebi-Ollenu, John Elliott
  - LM: Josh Hopkins, Bill Pratt, Barry Miller, Mike Drever, John Ringelberg, Frank Moore, Chris Norman, Caley Buxton, Selena Hall, Andy Scott
  - WUSTL: Bradley L. Jolliff
- Program Office Support:
  - JPL/Caltech Office of Competed Missions, Brent Sherwood
  - JPL/Caltech Office of Human/Robotic Missions, Garry Burdick
  - LM Civil Space Advanced Programs, Steve Price, Nick Smith

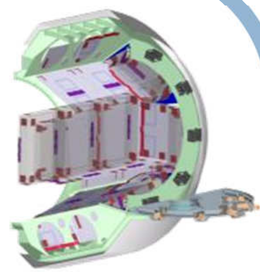
Orion/MoonRise Concept: Motivation

- Conduct an exciting and bold joint human-robotic mission to the Moon as a <u>precursor to future Mars</u> exploration using the mature Moonrise lander design.
- Accomplish high national priority Decadal Survey Science with the <u>first</u> sample return from the lunar farside, the <u>key</u> to understanding the formation of our Solar System.
- Define a new chapter in space exploration with joint human-robotic operations as an <u>integral part of mission success</u>.
- Engage the public and inspire a new generation of engineers by <u>demonstrating new technologies and systems</u>.

Initial Architectural Elements of the Study

Human Architectural Elements





Sample Airlock (LM)

INITIAL CAPABILITY

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

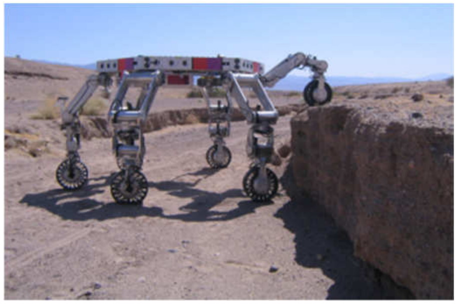
Orion Multi Purpose Crew Vehicle (JSC, LM)

Robotic Architectural Elements

MoonRise New Frontiers Phase A Study (JPL, LM)

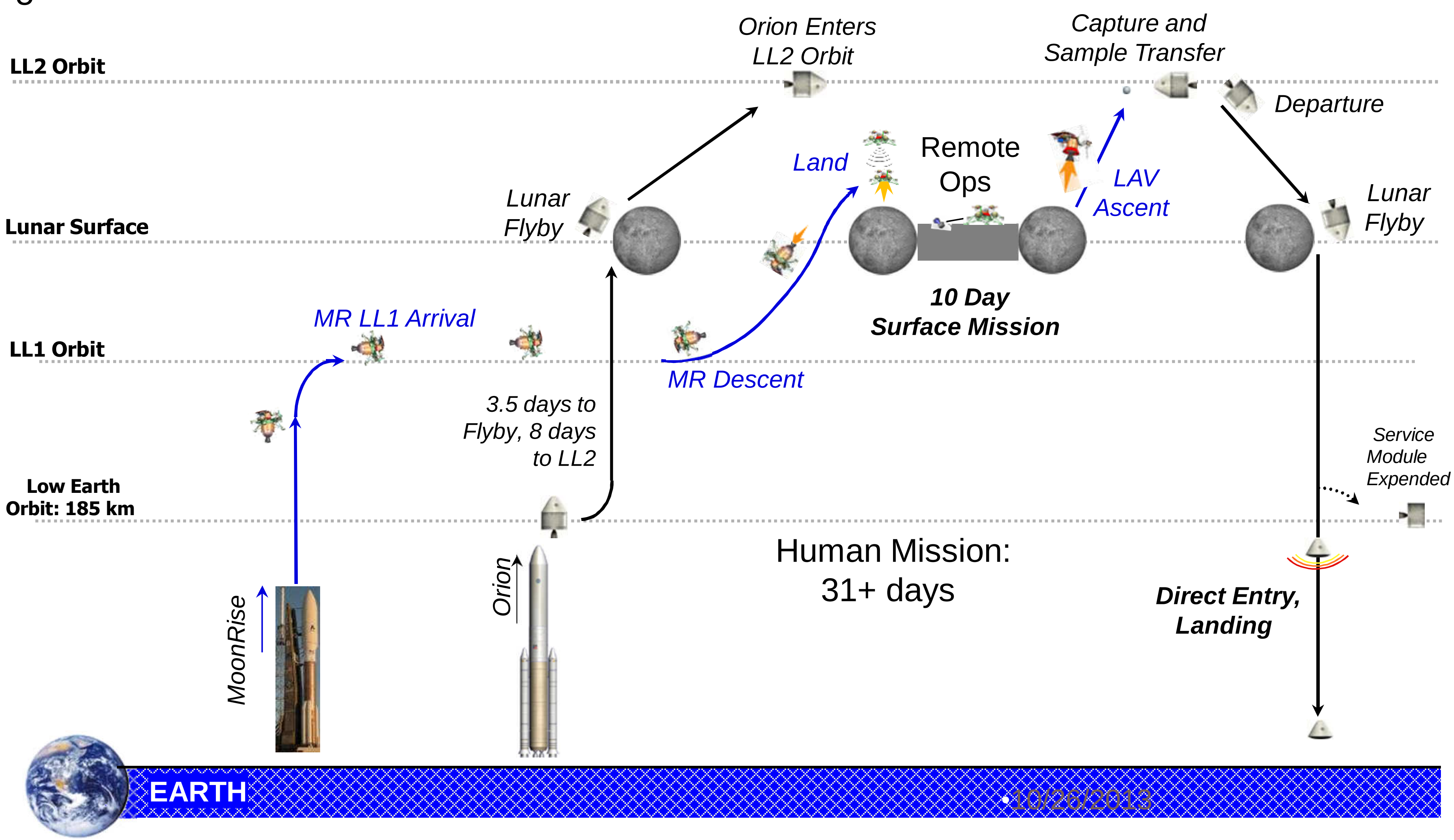
ALHAT: Autonomous Landing and Hazard Avoidance Technology (JSC, LaRC, JPL, APL, GRC)

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

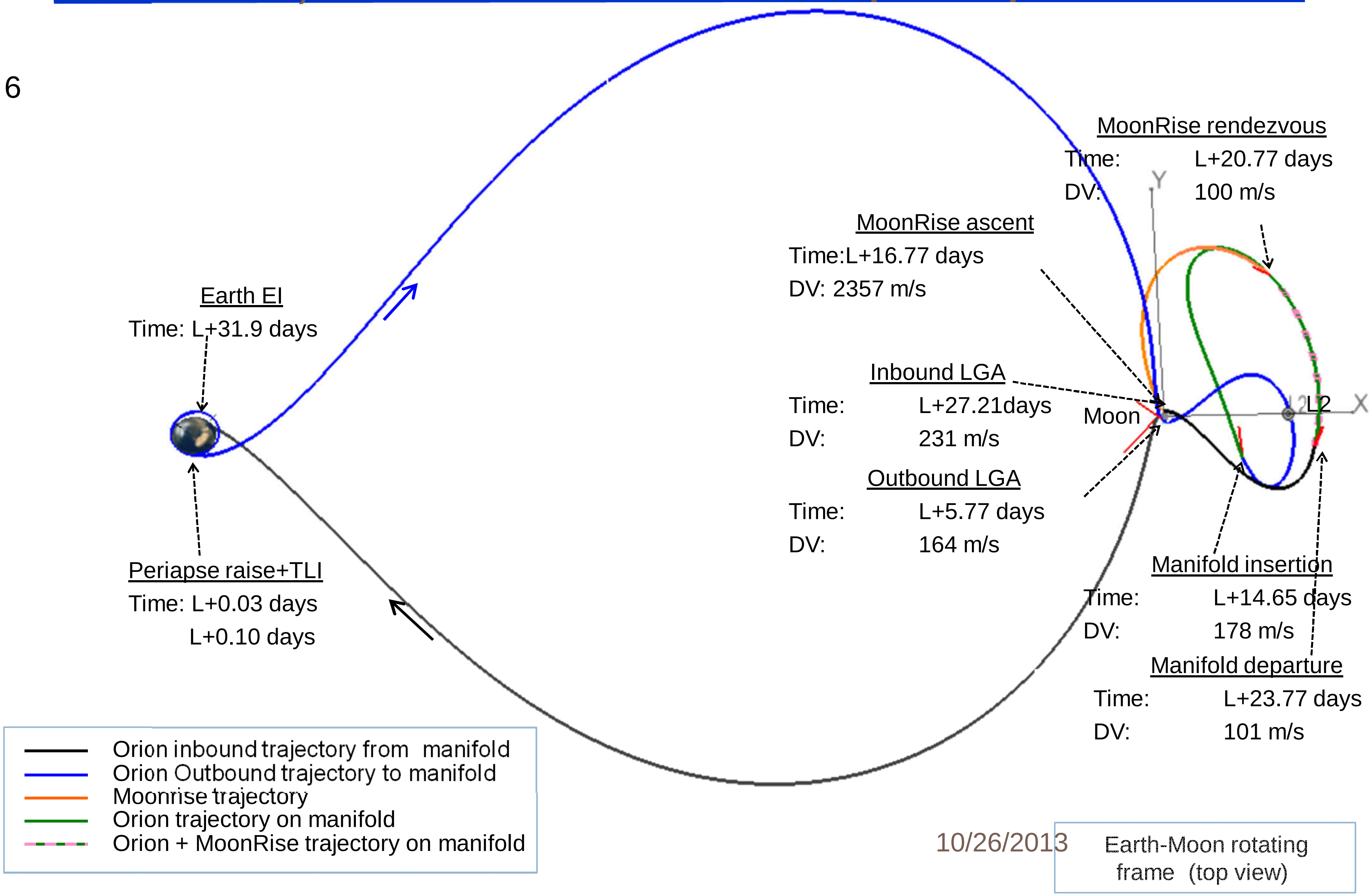


ATHLETE: Wheel-on-limb mobility for cargo offloading and rough terrain access (JPL)

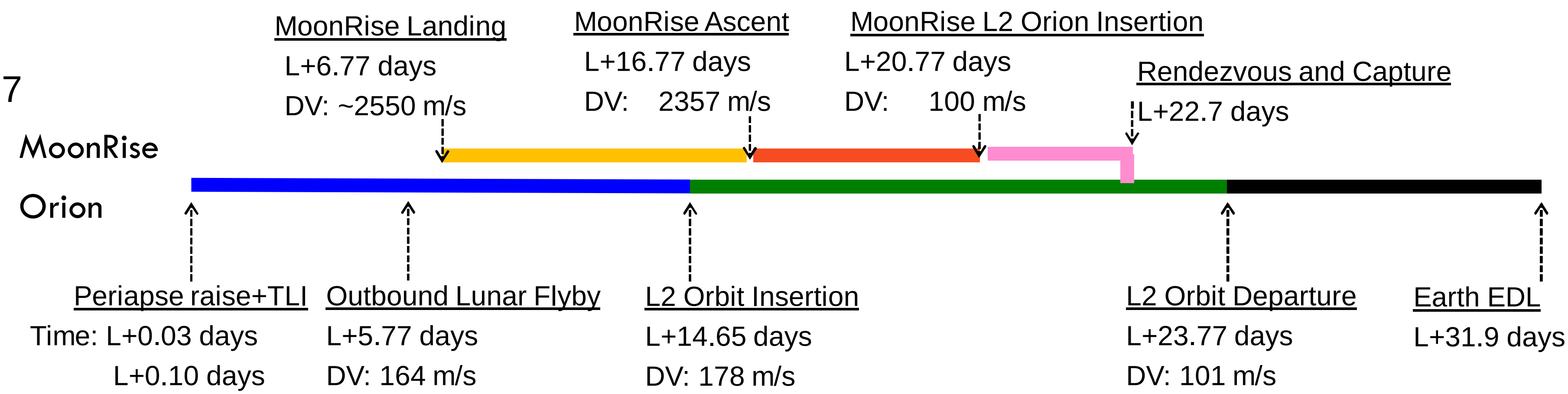
Orion/MoonRise Architecture



Orion/MoonRise baseline trajectory



Orion/MoonRise Trajectory: Key Parameters



Event	Event time (days)	Orion Delta-V (m/s)	Moonrise Delta-V (m/s)
iCPS Periapse Raise maneuver	L+0.03		
TLI maneuver	L+0.10		
Lunar Gravity Assist 1	L+5.77	164	
MoonRise landing (including soft landing costs)	L+6.77		(~2550)
Manifold insertion maneuver	L+14.65	178	
MoonRise ascent (on SRM)	L+16.77		2357.2
MoonRise manifold insertion maneuver	L+20.77		100
Sample canister transfer (statistical maneuvers)	L+22.77	*	*
Orion return maneuver	L+23.77	101	
Lunar Gravity Assist 2	L+27.21	231	
Orion Entry, Descent, Landing	L+31.9		

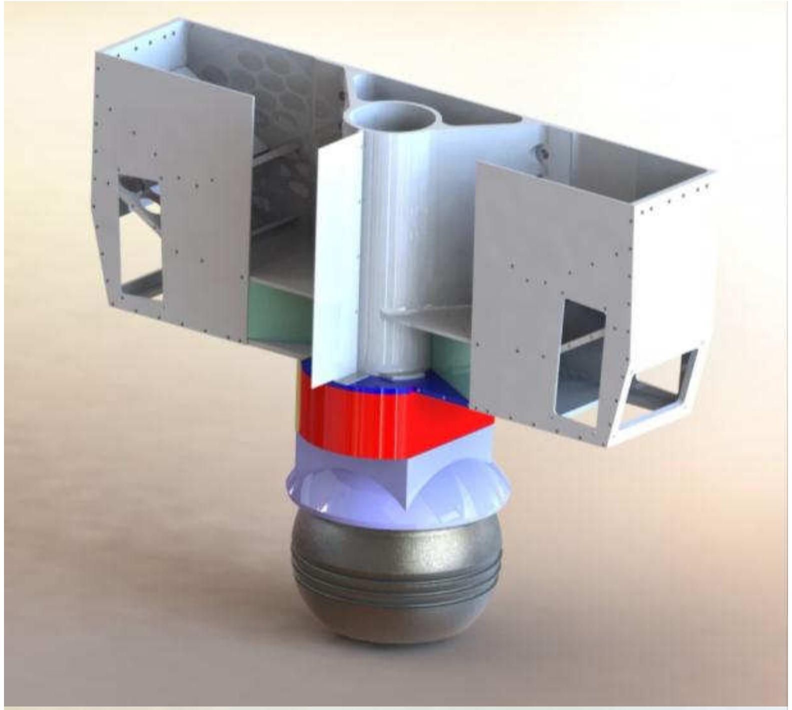
Background & Outline of Presentation

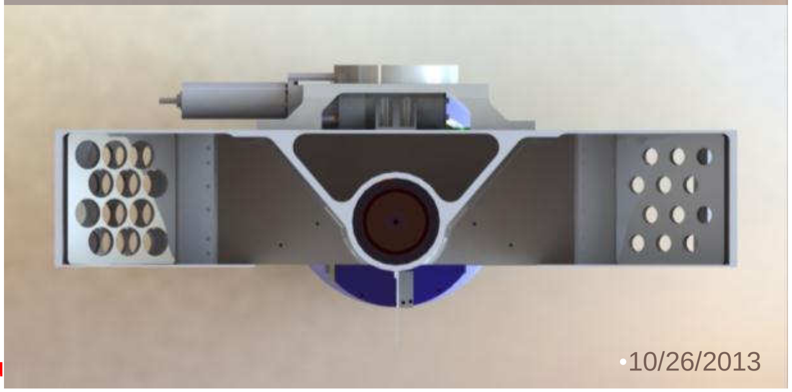
- LEAG 2012 presentation on Orion/MoonRise mission concept
- IEEE Aerospace Paper, March 2013
- Four questions asked at the LEAG 2012, including one by late Mike Wargo:
  1. Do you have a surface sampling and caching architecture for collecting more than 1 kg of samples?
  2. Did you look into the sample transfer approach by Orion?
  3. What is the proximity operations between LAV and Orion?
  4. What is the Mars Feed Forward approach?

SCALABLE SAMPLE COLLECTION APPROACH BASED ON MOONRISE

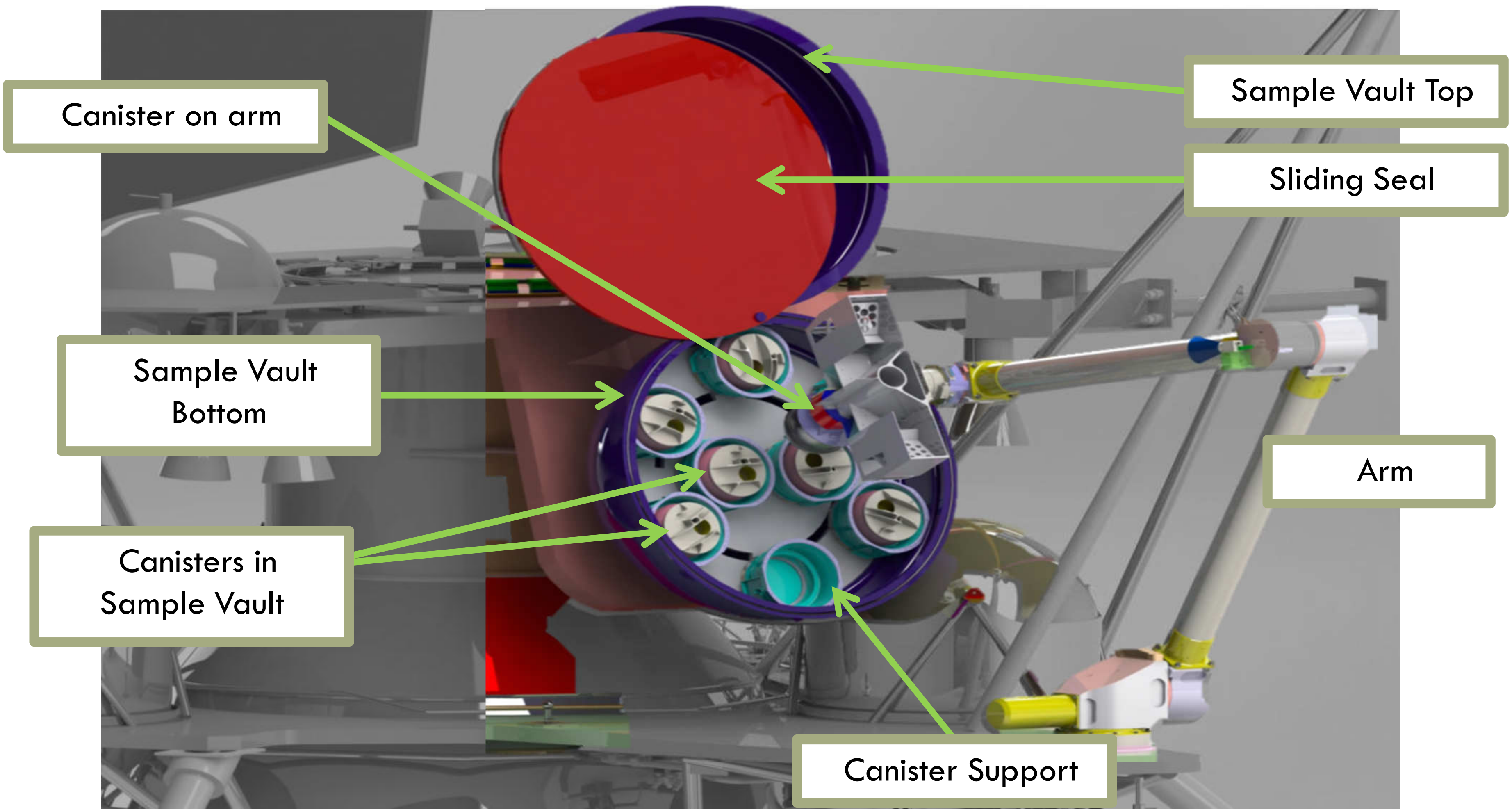
MoonRise Sampling: collect 1-2 kg/canister

- Bilaterally symmetrical compartments are outfitted with different grates to select different sample grades (sieves)
- Vibration motor induces sifting and sample containment in canisters
- Canister attachment mechanism enables the deposit and retrieval of multiple canisters





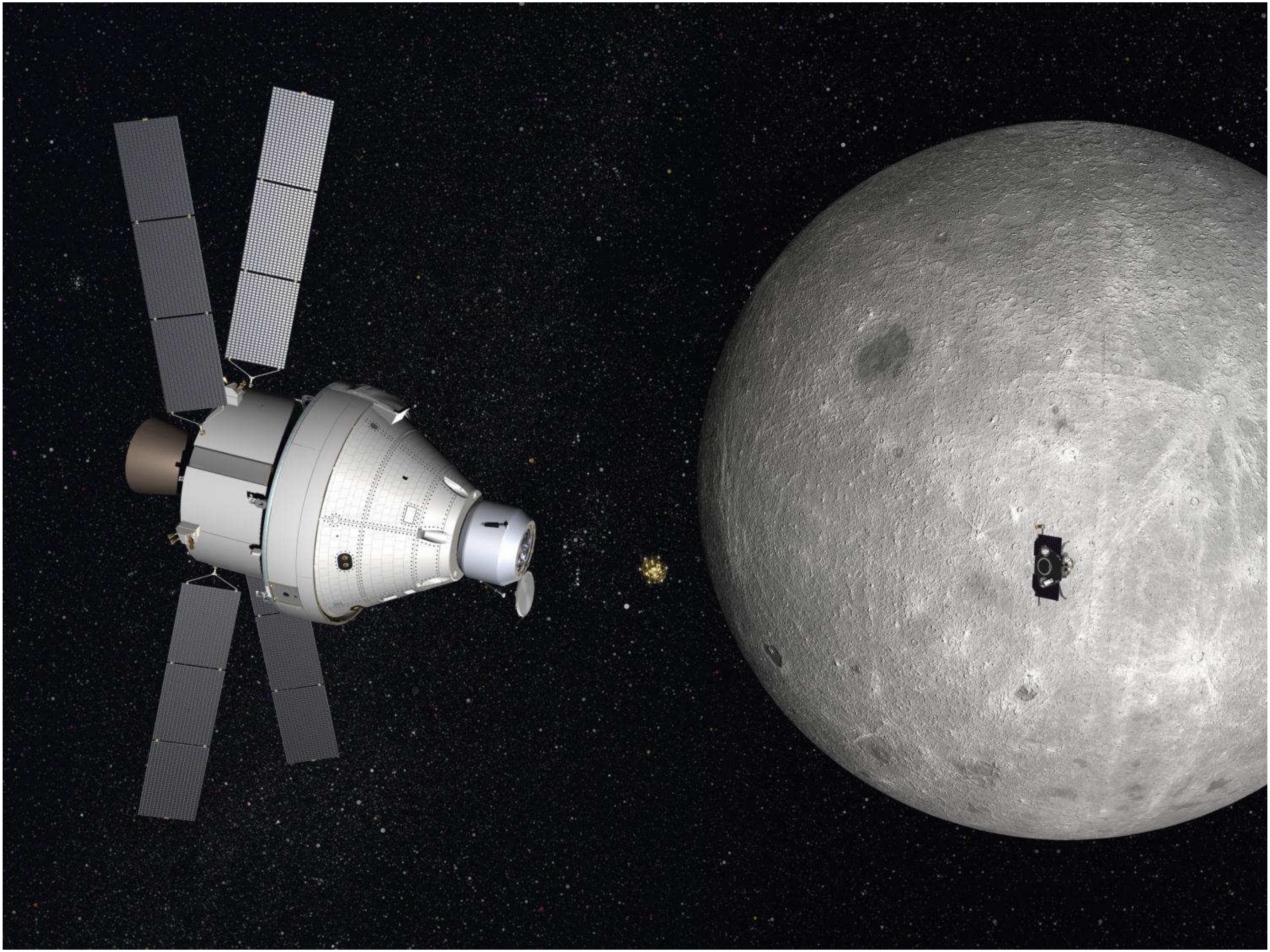
Multiple Canister Concept



Spherical Canister – Spherical Sample Vault

- ~20.3cm x 14.5cm diameter sample canisters
- Canisters are stored in ~60 cm diameter sample vault
- Spacing of the canisters can be optimized for increased sample storage
- Sample vault opens in a clamshell fashion
- A sliding circular sealing mechanism protectors canisters during operation
- Sealing mechanism opens and closes during canister retrieval and deposit

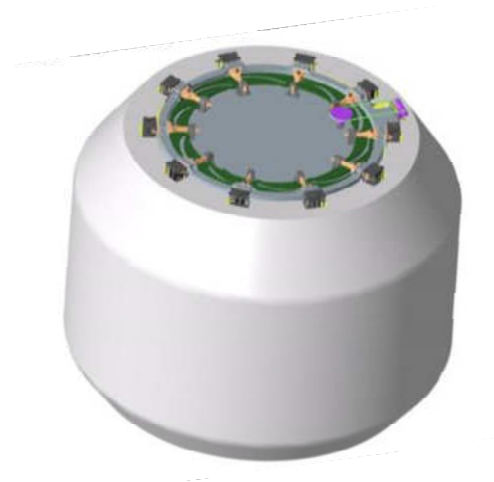
ORION PROXIMITY OPERATIONS AND SAMPLE TRANSFER



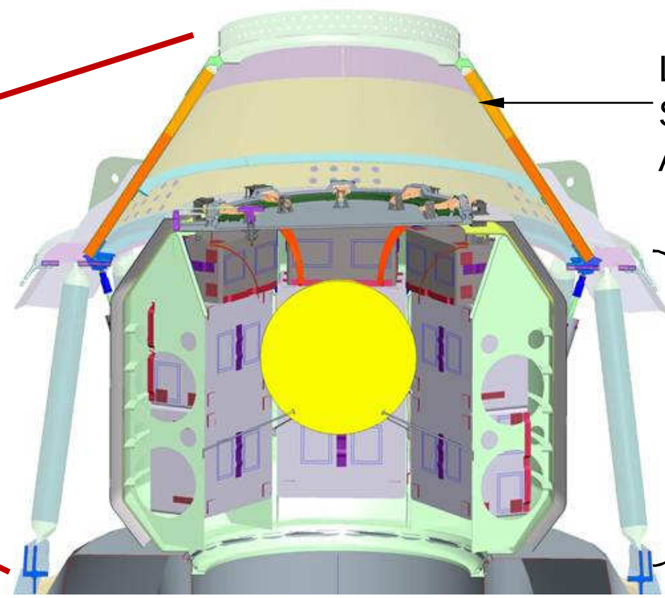
Sample Vault Expected Characteristics

- 24 inch (60 cm) diameter sphere
- 50 kg max total mass (Sample Vault empty + collected sample mass)
  - Max sample mass is determined in part by mass of Sample Vault
- Center of Mass may be offset from center of sphere
- Sample Vault may be spinning or tumbling up to a few RPM
- Sample Vault has 10-14 optical retroreflectors (corner cubes) for passive detection by Orion lidar (VNS)
  - Corner cubes are assumed to be flush-mounted in real Sample Vault, but are external protrusions in test article.
- Astronauts will be able to move Sample Vault to stow it, but will not open it
  - No manipulating samples, repackaging sample cans in other stowage, no exposure of astronauts to lunar dust

Sample Capture Airlock



Airlock can be used for sample capture and for added stowage volume. Airlock is jettisoned before reentry.



Launch Abort System Truss Assembly

Location available for small airlock in place of docking system

Crew Module Forward Tunnel and hatch

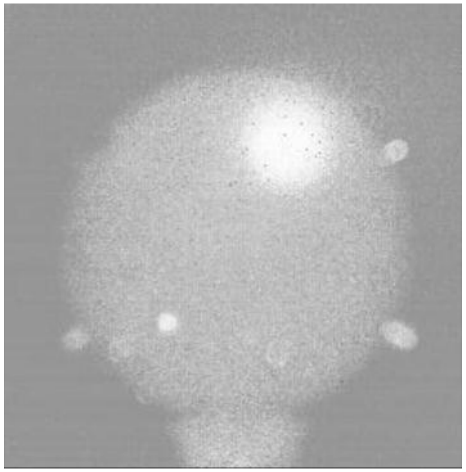
Orion Sample Capture and Return (OSCAR)

- Mission concept releases a passive Sample Vault in L2 halo orbit, then Orion approaches and captures it
  - The Lunar Ascent Vehicle would ascend, enter halo orbit, and use absolute navigation to approach within a few kilometers of Orion
  - Once Orion confirms detection of the LAV, the sample vault is released and LAV departs
  - Orion would then approach and capture the vault
  - Capture of a passive sample vault is traceable to Mars sample return and keeps LAV hazards away from Orion
- LM is testing sensors and software in the Denver Space Operations Simulation Center
  - A high fidelity, full scale, relative navigation test facility
  - Purpose of testing is to demonstrate feasibility of some Orion relative navigation functions for sample capture
    - Demonstrate that Orion can detect, differentiate, and track the sample container and LAV at initial range of 1 to 2 km
    - Demonstrate 3-dof relative position determination of the sample container for approach and capture (testing from 60 m range to capture)

Orion Sample Capture and Return (OSCAR)

- Summary of testing completed so far
  - Orion VNS lidar detected retroreflectors on Sample Vault at ranges of 1032 and 2030 meters
  - Simulated sample vault separation from ascent vehicle to determine delineation point for tracking with various sized retroreflectors
  - Collected approach imaging of sample vault from 60 m while stationary and rotating
    - Corner cubes are highly visible, also getting additional returns from metallic features on mockup
    - Optimizing container configuration as a passive target for Orion sensors
- Testing will continue through end of 2013
  - Evaluate relative position determination capabilities in nominal and adverse conditions
  - Test additional IRAD-developed relative nav software
  - Culminate with a series of closed-loop approaches to capture point

Sample Vault mockup mounted on robot arm



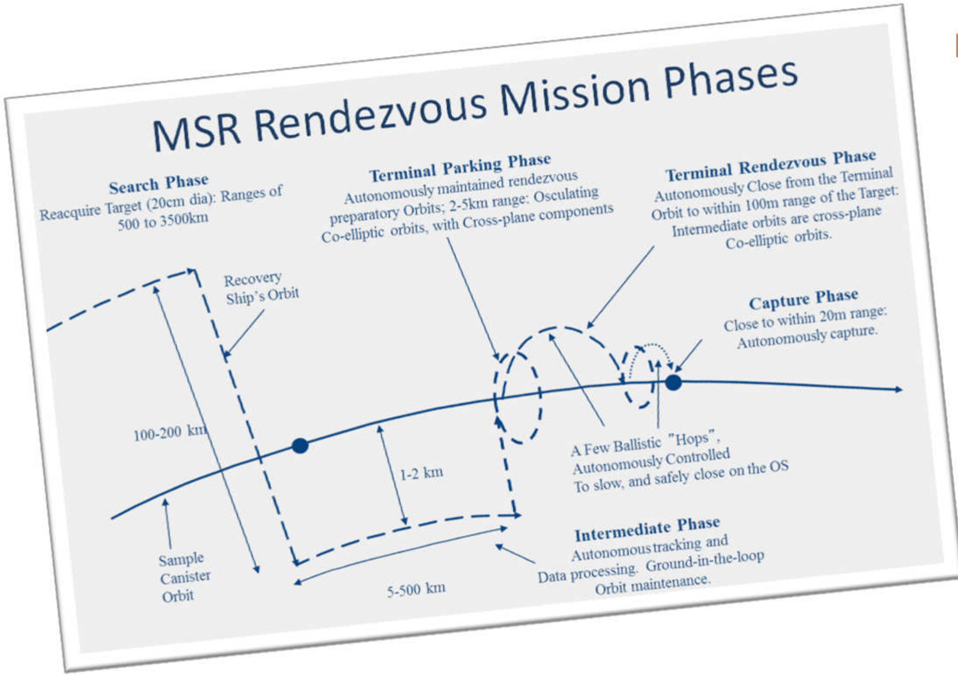
Orion Lidar view of Sample Vault

MARS FEED-FORWARD

Mars Feed Forward

- Sample capture system demonstrates concepts needed for robotic sample capture at Mars
  - Design of Orion/Moonrise system coordinated with Mars Sample Return mission concept study
- Remote operation of surface activities may feed directly into concepts for early human Mars exploration (non-landed) missions

Sample Capture



- For Mars Sample Return (MSR) Passive Optical tracking of the orbital sample canister (OS) was chosen as the baseline, with a back-up radiometric beacon, because
  - Passive optical can be operational in all phases of the search, rendezvous and capture
  - It does not *require* active components aboard the OS
  - DS1 and Deep Impact AutoNav is flight-heritage and can implement the OS-relative Nav, approach and capture
- The Orion/MoonRise concept has adopted passive optical tracking as well, to provide maximum feed-forward to MSR missions

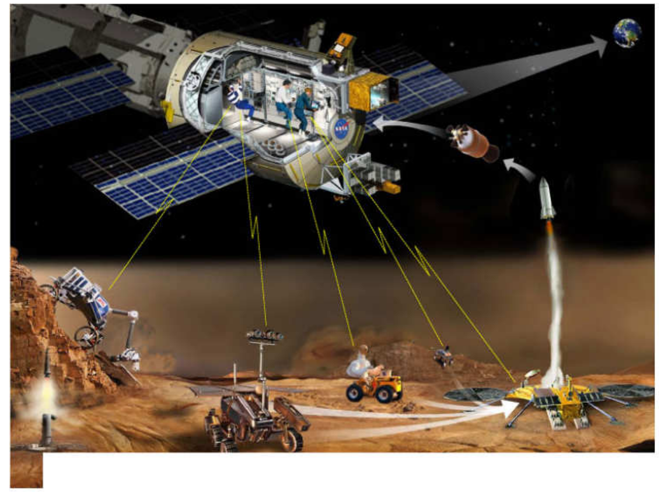
Tele-presence

- Remote operation of surface activities may feed directly into concepts for early human Mars exploration (non-landed) missions
- GSFC Symposium explored value of telepresence for human exploration

  Findings for Human Exploration included:

  Telepresence . . .

  - *Enables human operations in hostile, inaccessible, or limited access environments.*
  - *Enables improvisation in quick response to changing conditions, expanding the range of environments in which human activity can be undertaken: challenging surfaces, pinpoint landing, operating outside human habitats*
  - *Reduces mission risk through improved situational awareness, being able to react to the unexpected/unplanned.*
  - *Offers an immediacy of interactive experience that significantly enhances STEM education at all grade levels. It offers similar experience for public outreach in participatory exploration.*



Space Exploration Enabled by Telepresence: Combining Science and Human Exploration

Based on Findings from:
"Exploration Telerobotics Symposium"
May 2-3, 2012
NASA Goddard Space Flight Center

Azita Valinia (NASA GSFC), Harley Thronson (NASA GSFC), Jim Garvin (NASA GSFC), George Schmidt (NASA GRC), & Dan Lester (Univ of Texas)

http://telerobotics.gsfc.nasa.gov/

October 4, 2012

Tele-presence

- Recent experiments aboard ISS have taken the first step, confirming the viability of tele-operation from Earth orbit
- Astronauts remotely surveyed area, then deployed simulated radio telescope antenna using K-10 robot
  - Follow-up test used robot to inspect installation

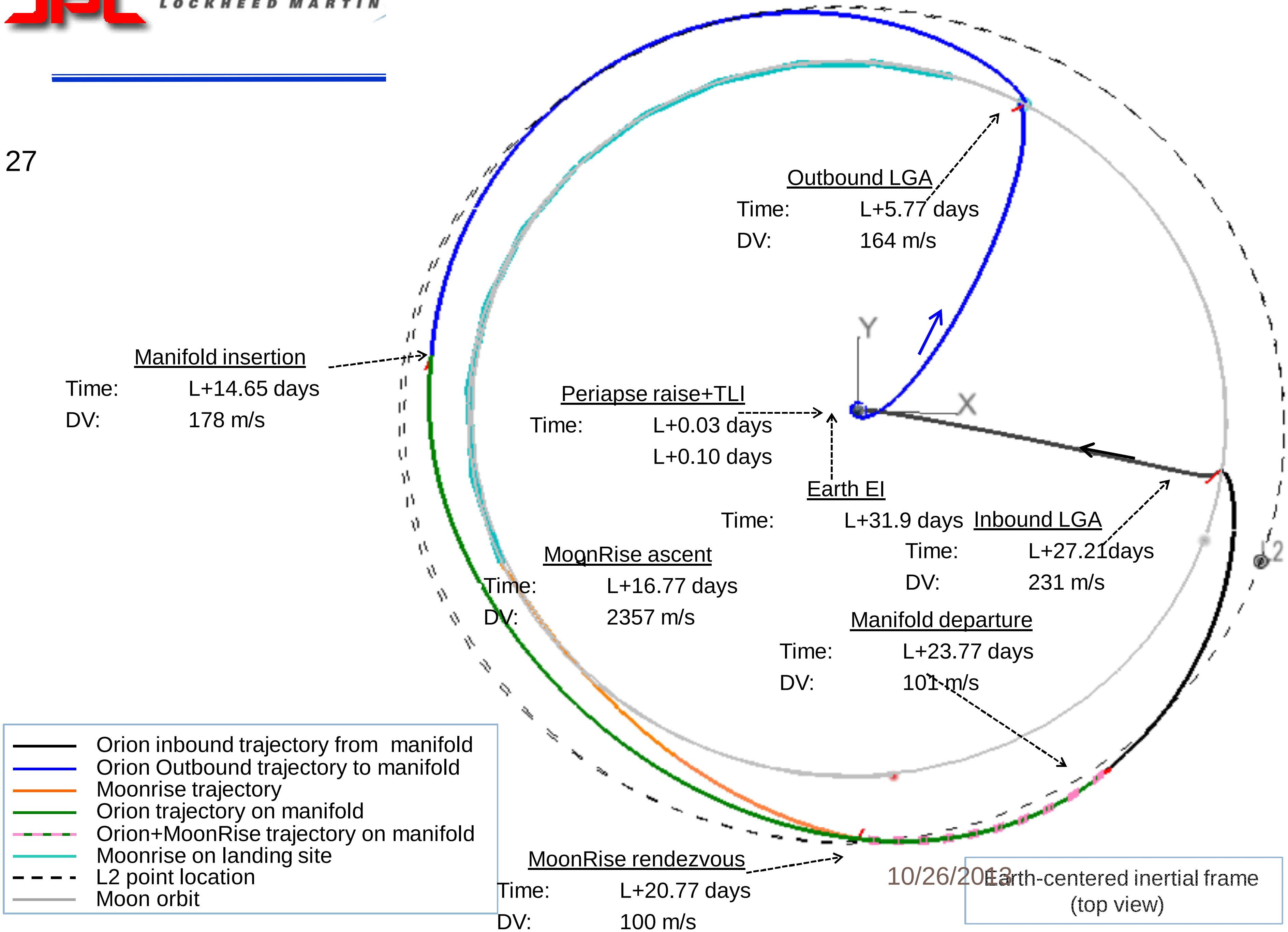
Conclusion

- The joint JPL, LM & WUSTL Team worked together to answer the four questions raised at the LEAG 2012 meeting:
  - Sample collection architecture
  - Sample transfer architecture
  - Orion Proximity operations
  - Mars Feed-forward approach

- Future Work:
  - Orion – MoonRise surface operations tele-operations architecture

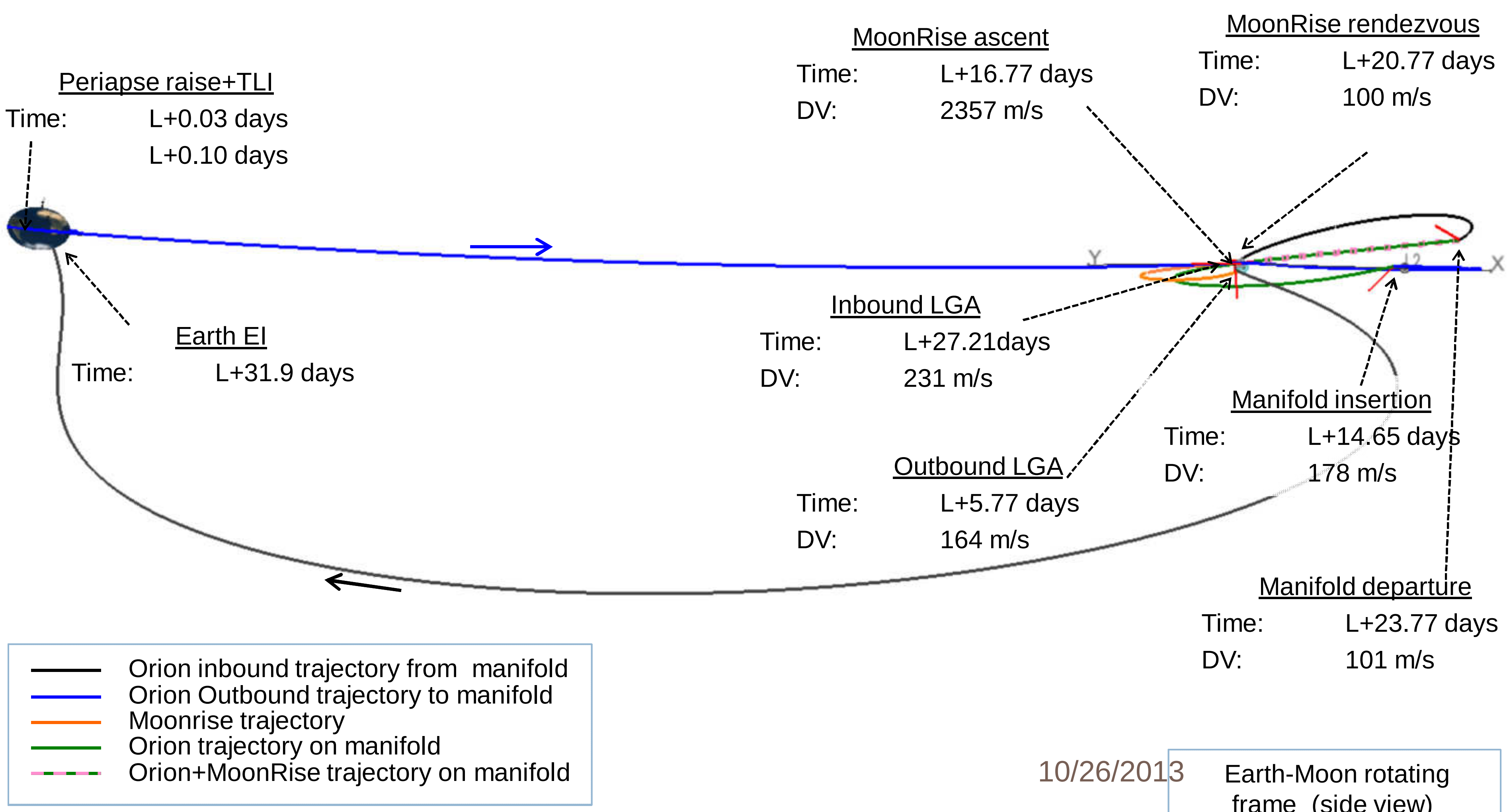
BACKUP

Trajectory animation



Outbound LGA
Time: L+5.77 days
DV: 164 m/s
Manifold insertion
Time: L+14.65 days
DV: 178 m/s
Periapse raise+TLI
Time: L+0.03 days
L+0.10 days
Earth EI
Time: L+31.9 days
Inbound LGA
Time: L+27.21days
DV: 231 m/s
MoonRise ascent
Time: L+16.77 days
DV: 2357 m/s
Manifold departure
Time: L+23.77 days
DV: 101 m/s
MoonRise rendezvous
Time: L+20.77 days
DV: 100 m/s
Y
X
L2
Orion inbound trajectory from manifold
Orion Outbound trajectory to manifold
Moonrise trajectory
Orion trajectory on manifold
Orion+MoonRise trajectory on manifold
Moonrise on landing site
L2 point location
Moon orbit
Earth-centered inertial frame
(top view)

Orion/MoonRise Trajectory



Earth-Moon rotating frame (side view)