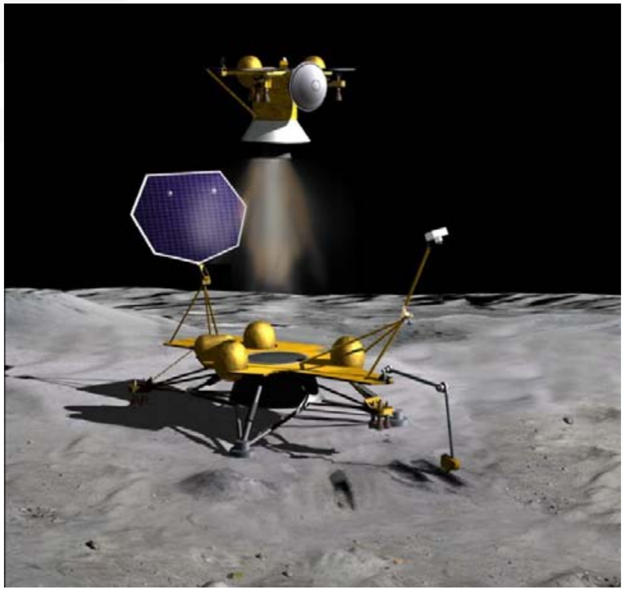
Lunar Sample Return via Cis-lunar Space

John Connolly/NASA – JSC

4 March 2013

Lunar Sample Return via Cis-Lunar Space

- **South Pole Aitken Basin (SPAB) sample return scenario**
  - Robotic launch to SPAB on the far side of the moon
  - 14 day science and technology mission
  - Up to 5 kg of lunar samples (rocks and regolith) placed into sample container
  - Sample container launched to Cis-lunar space
  - Rendezvous with crewed vehicle in cis-lunar space
  - Sample capture
  - Sample transfer into crew cabin for return to Earth
- **Desirable attributes**
  - Preservation of lunar volatiles
  - Extensibility to asteroid and Mars sample return missions (including planetary protection)
- **Two options**
  - Sample return via a cis-lunar spacecraft
  - Sample return using Orion only



Sample Return Mission ConOps-

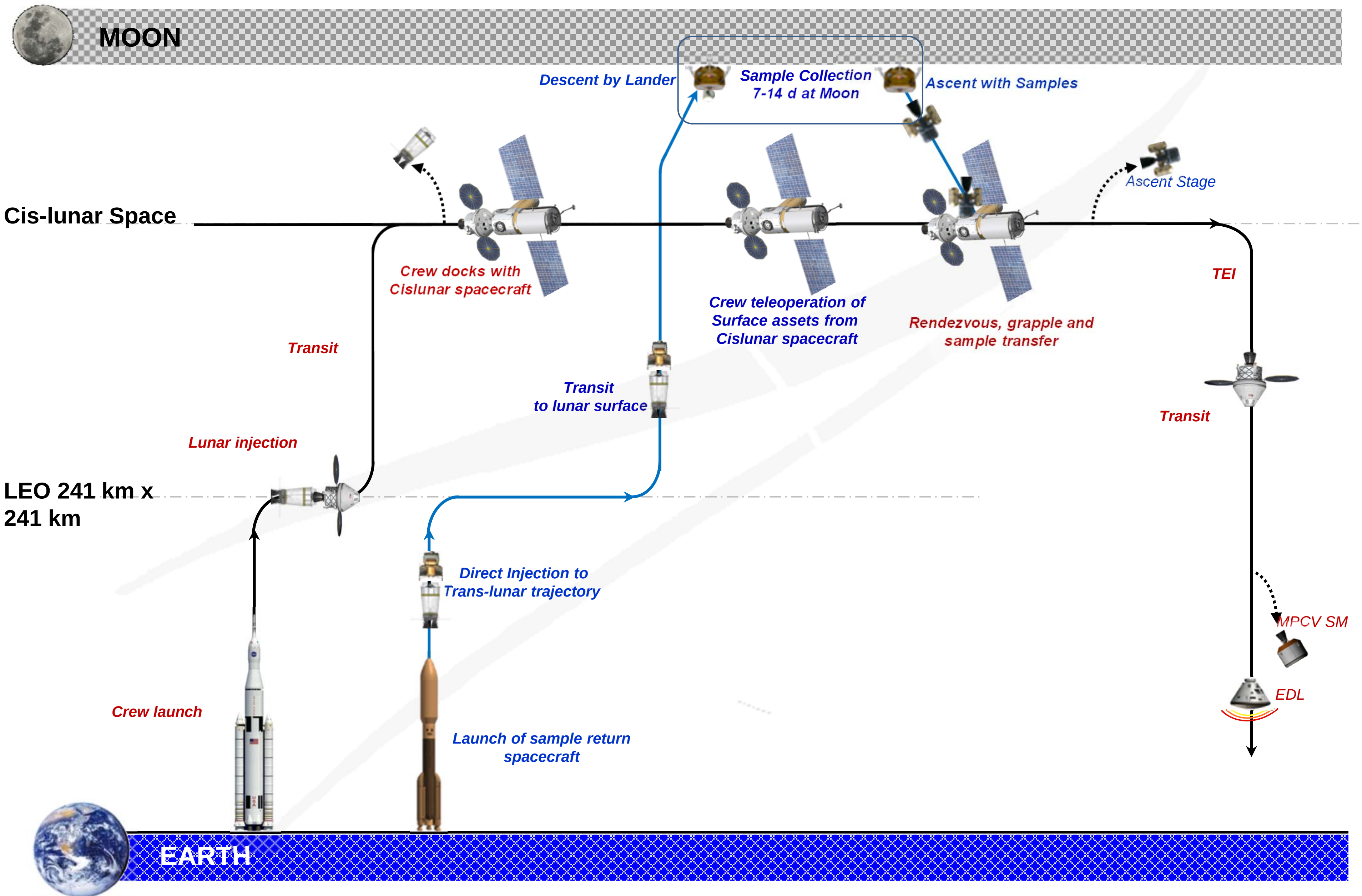
- **Assume a sample mass of 5 kg/5 liters for a robotic sample return mission to a Cis-lunar spacecraft**
  - 1 kg of small rocklets for science has a volume that is roughly 1 liter
  - 4 kg of regolith primarily for ISRU (3 liters)

- **Sample acquisition – Scooping/sieving required to produce the required number of rocklets for scientific purposes and soil for technology use**

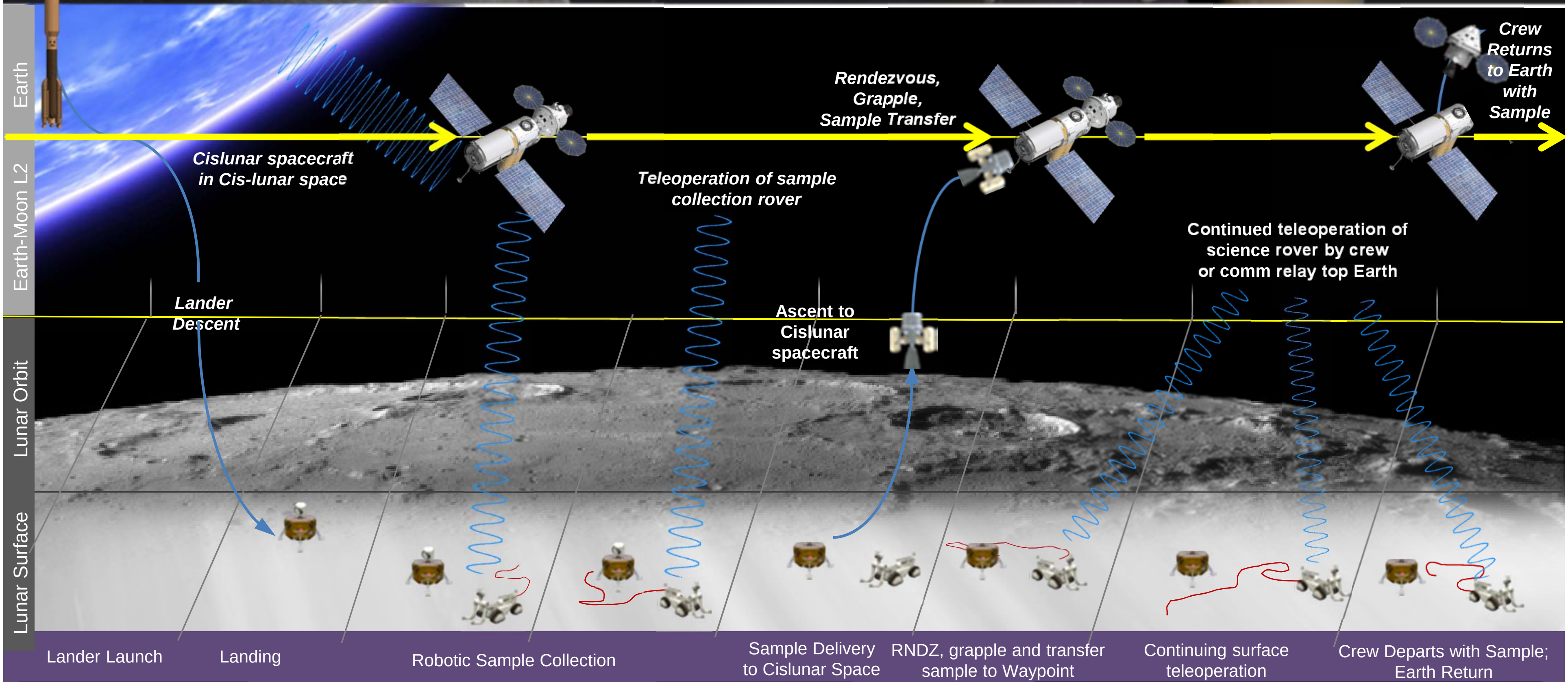
- **Sample Return Vehicle**
  - Arrives in a stable orbit in cis-lunar space
  - Sample Container (OS)
  - Orbital maintenance capability

- **ConOps will vary for volatile sample returns, asteroid sample return (preservation of water and organics for certain types of asteroids) and Mars sample return missions (planetary protection emphasis)**

Example Lunar Sample Return via Cis-Lunar Space - With Cis-lunar Spacecraft



Example Robotic + Human-Assisted Lunar Sample Return via Cis-Lunar Space with Cis-lunar Spacecraft



Mission Summary

- Crewed spacecraft operating in cis-lunar space
- Crew transit to Cis-lunars pacecraft in Orion
- Sample return mission launched on EELV, transits to moon and performs descent to surface
- Crew in Cislunar spacecraft begin teleoperation to collect lunar samples
- Sample collection rover loads samples into Lunar Ascent Vehicle (LAV)
- LAV performs ascent to proximity of Cis-lunar spacecraft
- Sample grappled and transferred into Cis-lunar spacecraft
- Crew and samples depart Cis-lunar spacecraft and return to Earth

Elements

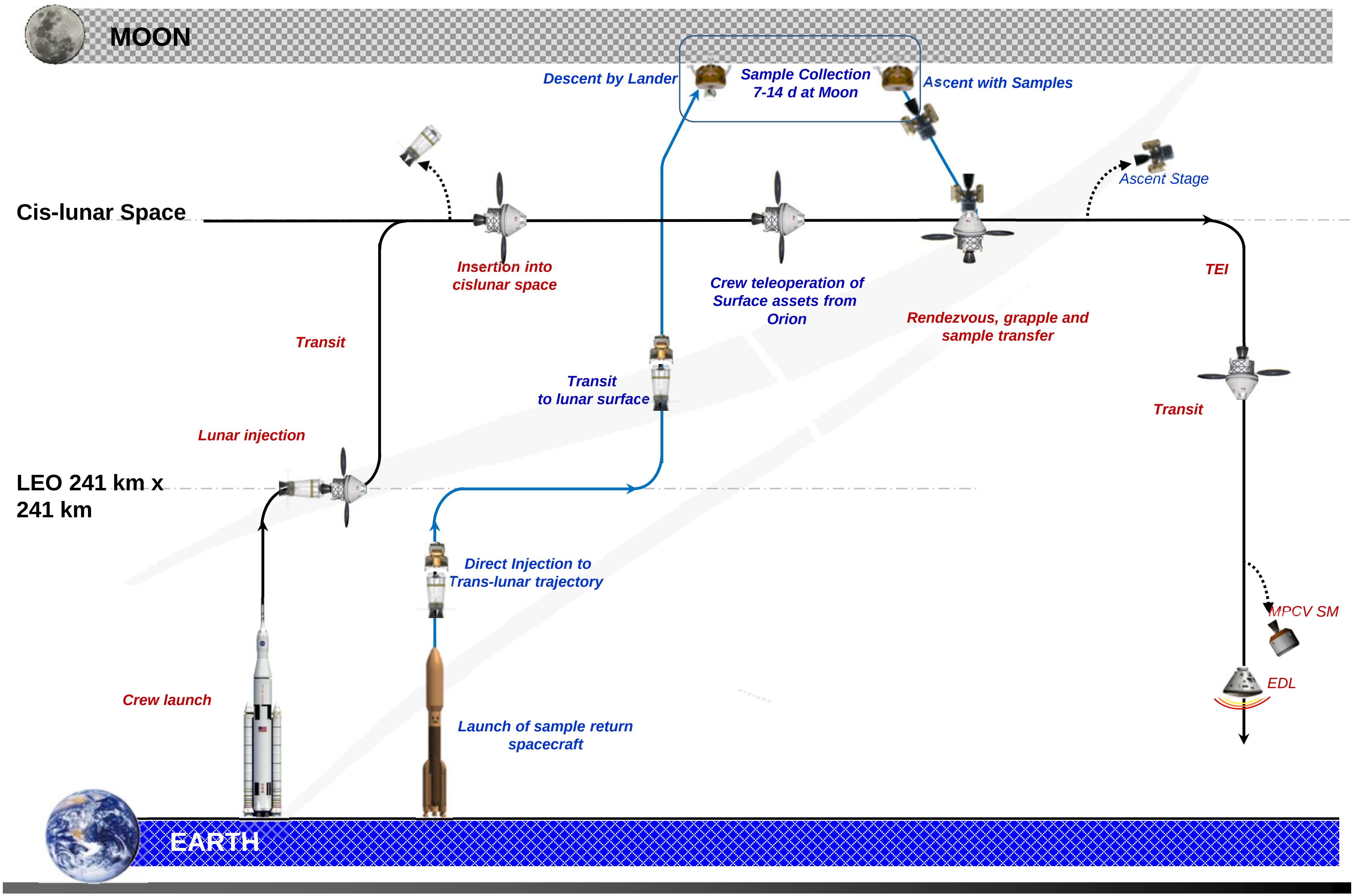
- SLS
- Orion + Crew
- Robotic mission launch vehicle
- Robotic lander with rover, sample cpntainer and lunar ascent vehicle
- Cis-lunar spacecraft

Mission Assumptions & Connectivity

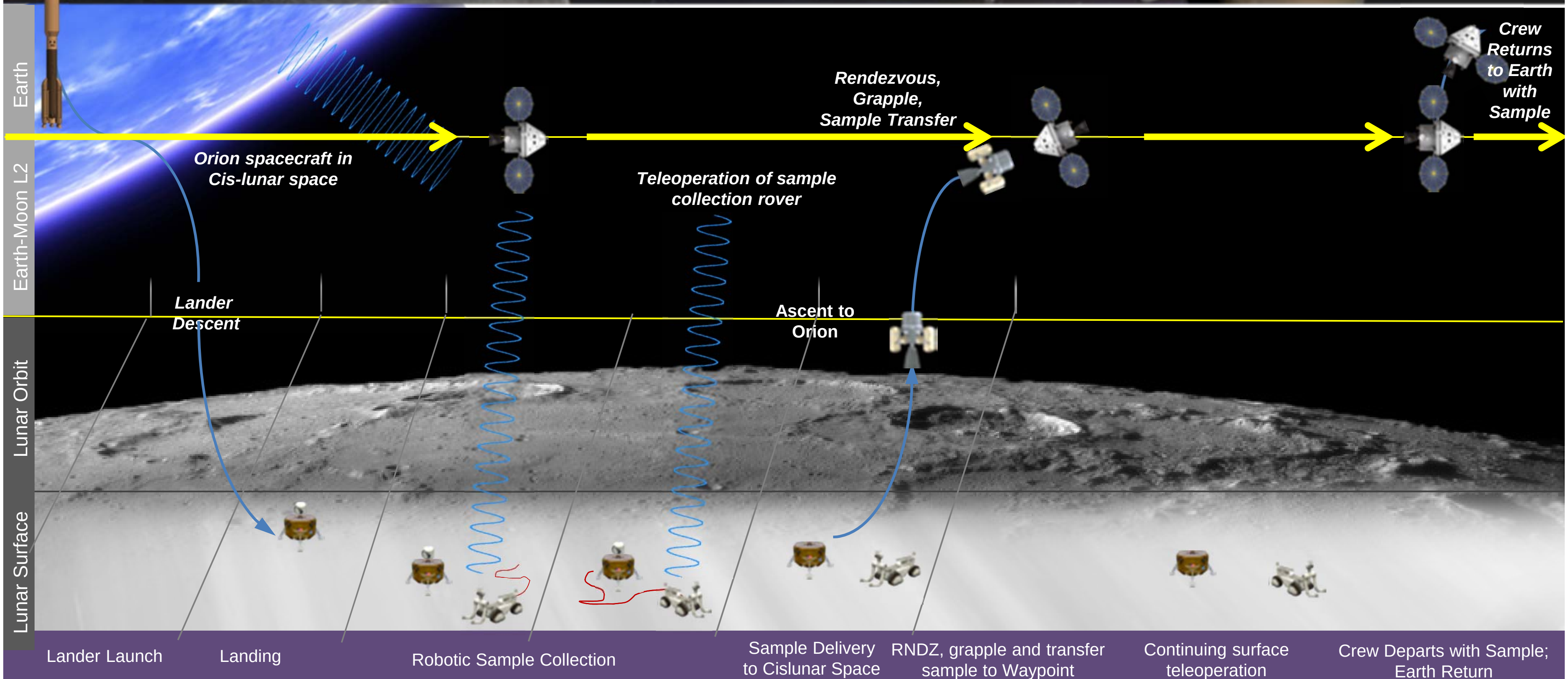
- Direct teleoperation of surface sampling system from Cis-lunar spacecraft greatly reduces communications latency
- Small rover(s) may continue to be operated over extended duration after crew departs if the cis-lunar spacecraft provides communications relay capability to Earth

Removed per STIPO request 6/17/13

Example Lunar Sample Return via Cis-Lunar Space - With NO Cis-lunar Spacecraft (Orion only)



Example Robotic + Human-Assisted Lunar Sample Return via Cis-Lunar Space with NO Cis-lunar Spacecraft (Orion only)



Mission Summary

- No other spacecraft operating in cis-lunar space
- Crew transit to Cis-lunar space and operates mission from Orion
- Sample return mission launched on EELV, transits to moon and performs descent to surface
- Crew in Orion teleoperation to collect lunar samples
- Sample collection rover loads samples into Lunar Ascent Vehicle (LAV)
- LAV performs ascent to proximity of Orion
- Sample grappled and transferred into Orion
- Crew and samples depart Cis-lunar space and return to Earth

Elements

- SLS
- Orion + Crew
- Robotic mission launch vehicle
- Robotic lander with rover, sample cpntainer and lunar ascent vehicle

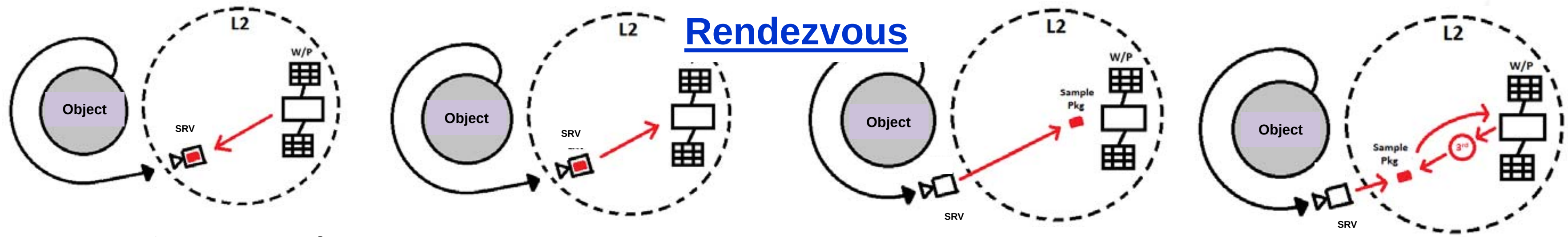
Mission Assumptions & Connectivity

- Direct teleoperation of surface sampling system from Orion greatly reduces communications latency
- Sampling rover could continue to be operated if a communications relay is available to Earth

Removed per STIPO request 6/17/13

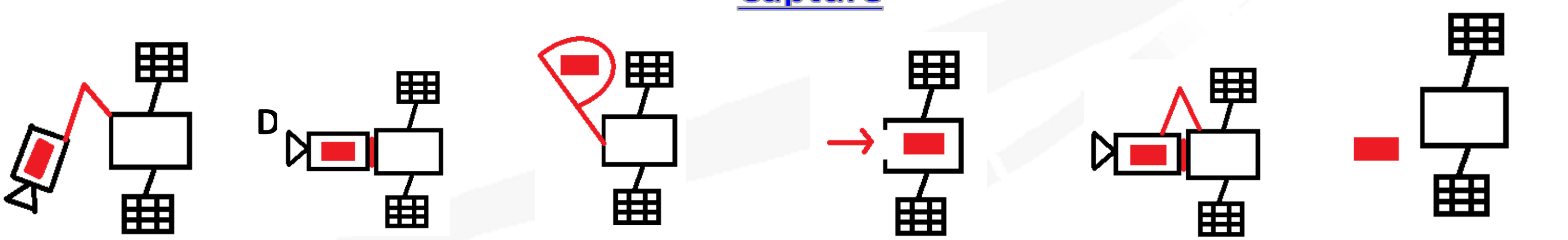
Rendezvous, Capture, Transfer Options

Rendezvous



Active Crewed SC | Active SRV | Active Sample | Active 3rd Element

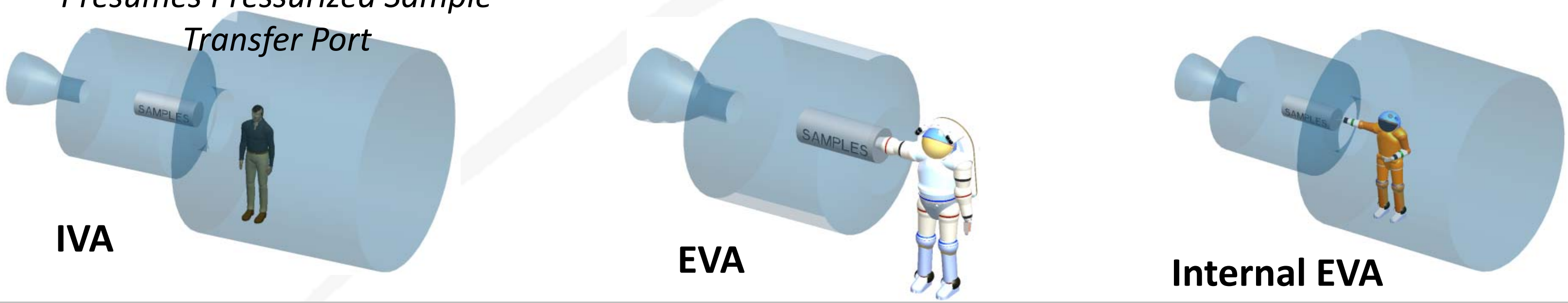
Capture



Grapple | Dock | Catch | Consume | Berth | Formation Flying

Transfer

Presumes Pressurized Sample Transfer Port



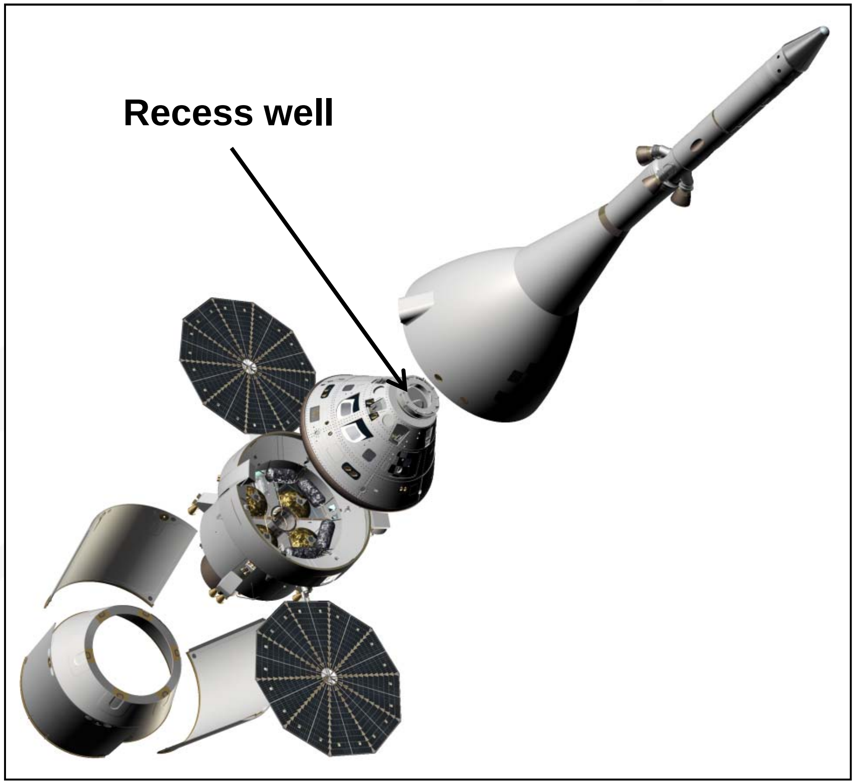
IVA | EVA | Internal EVA

Sample Return Element/Function Matrix

Element	**Option A** *Orion Chases SRV; EVA Retrieval*	**Option B** *Robonaut Chases SRV; Returns OS to Sample Transfer Airlock*	**Option C** *Active GWSC grapples SRV; "Hatch" EVA transfer*	**Option D** *Active SRV captured by GWSC; OS to Sample Transfer Airlock*	**Option E** *Active SRV Docks to GWSC; IVA Sample Transfer*
Sample Return Vehicle (SRV)	☑ Insert sample into TBD orbit	☑ Insert sample into TBD orbit	☑ Insert sample into TBD orbit	☑ Insert sample to GWSC orbit	☑ Insert sample to GWSC orbit, perform R&D
Sample canister	☑	☑	☑	☑	☑
GWSC robotic arm (Grapple)				☑	
EVA capability (airlock + EVA suits)	☑ Orion		☑ GWSC Node		
Sample Transfer Airlock		☑ On GWSC		☑ On GWSC	
Docking Port					☑ On GWSC
Rendezvous functionality (GN&C, ACS, Propulsion, communications)	☑ Orion	☑ Robonaut	☑ Gateway	☑ SRV	☑ SRV
Orion	☑ Active chase s/c, EVA capable	☑	☑	☑	☑
Robonaut		☑ Active chaser; RNDZ capability			
Sample Acquisition System	☑	☑	☑	☑	☑
Landing Stage	☑	☑	☑	☑	☑

Sample Return Element/Function Matrix

Element	**Option F** *Orion Chases SRV; Capture into recess well left by the Launch Abort System (LAS)*	**Option G** *Orion Chases SRV; EVA Retrieval*
Sample Return Vehicle (SRV)	☑ Insert sample into TBD orbit	☑ Insert sample into TBD orbit
Sample canister	☑	☑
GWSC robotic arm (Grapple)		
EVA capability (airlock + EVA suits)		☑
Sample Transfer Airlock		
Docking Port		
Rendezvous functionality (GN&C, ACS, Propulsion, communications)	☑ Orion	☑ Orion
Orion	☑ Active chase s/c	☑ Active chase s/c
Robonaut		
Sample Acquisition System	☑	☑
Landing Stage	☑	☑

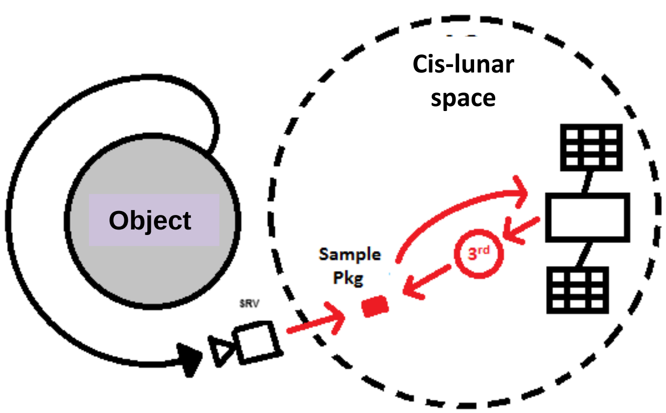


Option A Details

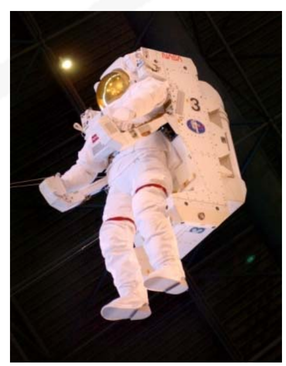
Sample Return Vehicle	GW Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar space	• No impact to Cis-lunar spacecraft

Transfer

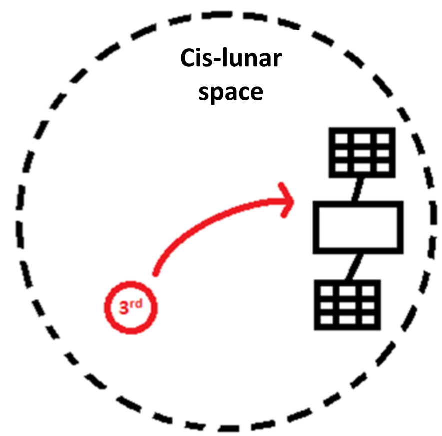
- Active Orion rendezvous with SRV
- EVA sample retrieval and transfer to Orion



1. Orion performs RNDZ with SRV



2Crew performs EVA to retrieve sample container (OS)



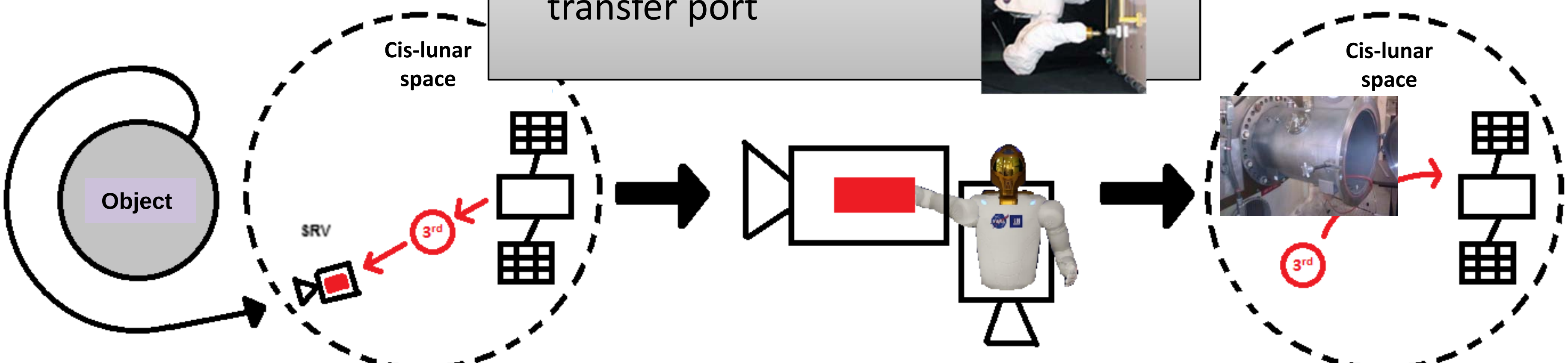
3. Orion returns to Cis-lunar spacecraft or directly to Earth

Option B Details

Sample Return Vehicle	Cis-lunar Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar spce • Sample container designed for manipulation by Robonaut	• Robonaut stored externally (w/docking, power, thermal, etc. provided) • Cis-lunar spacecraft active to w/in 1 km of SRV • Sample transfer airlock with external robotic access

Transfer

IVA: crew accessible sample transfer port



1. Cis-lunar spacecraft sends Robonaut with jetpack to SRV

2. Robonaut retrieves samples from SRV

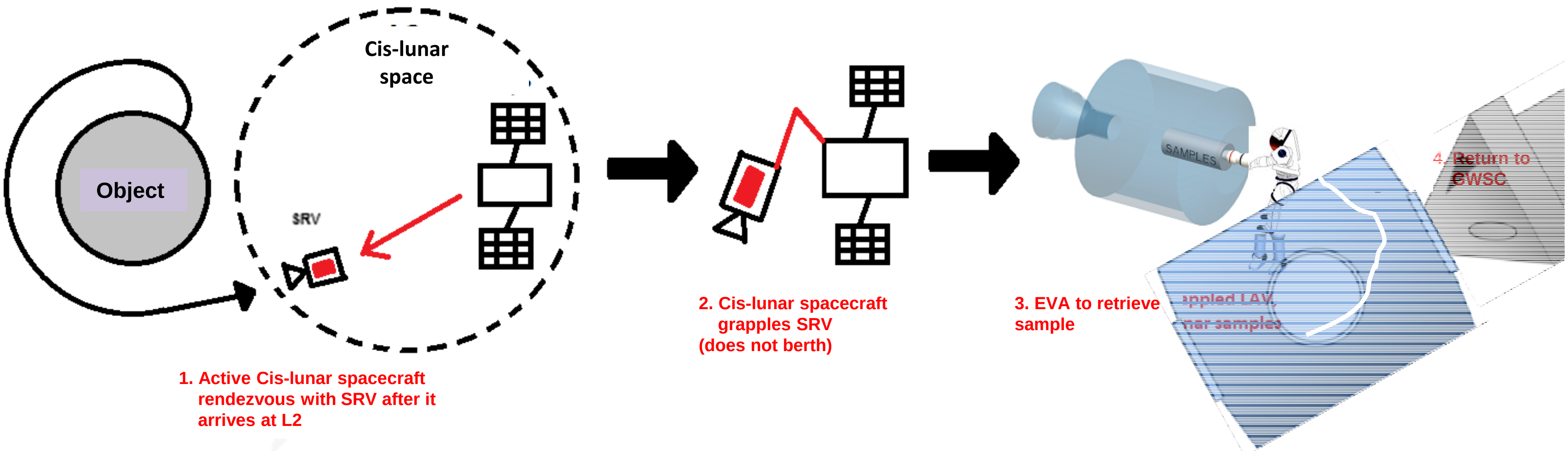
3. Robonaut returns to Cis-lunar spacecraft and places samples in sample airlock for IVA transfer

Option C Details

Sample Return Vehicle	Cis-lunar Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar space • EVA-Accessible Sample Package location	• Active rendezvous capability; to TBD m of the SRV • Robotic grapple arm, EVA Hatch • Umbilical EVA capability

Transfer

- Via EVA Hatch

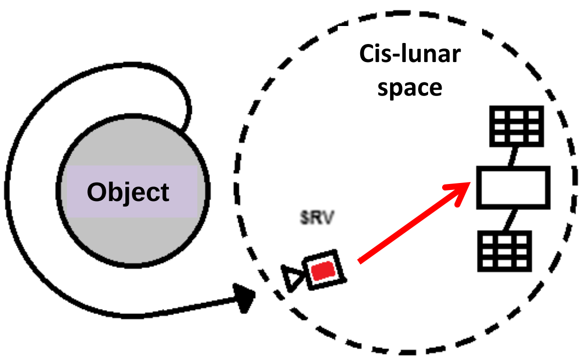


Option D Details

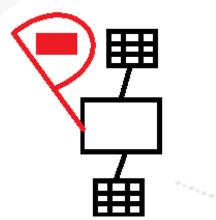
Sample Return Vehicle	Cis-lunar Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar space • Maneuvers within TBD m of Cis-lunar spacecraft	• TBD capture mechanism ("catchers mitt") • Sample transfer airlock

Transfer

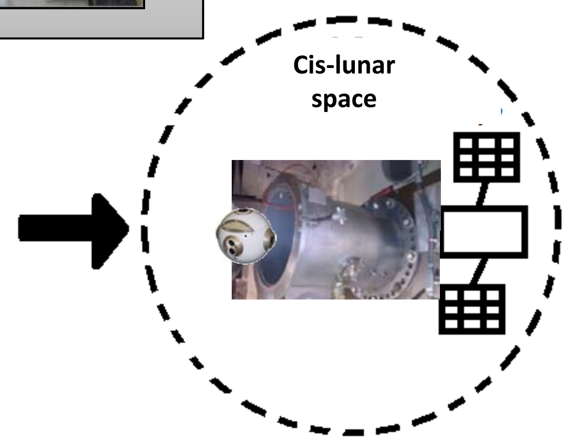
- Via sample transfer lock or suit port transfer module



1. Active SRV rendezvous with Cis-lunar spacecraftafter it arrives at L2



2. Cis-lunar spacecraft captures OS (does not berth)



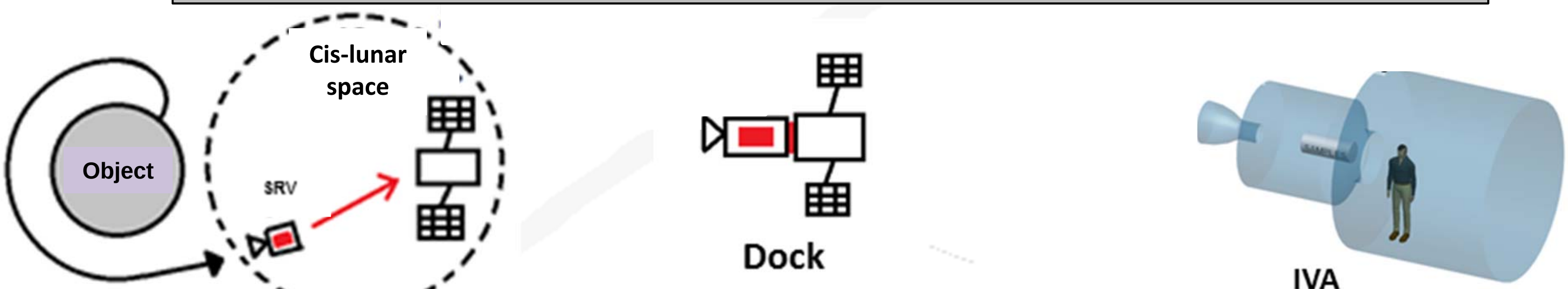
3. Capture device places samples in transfer airlock for IVA transfer

Option E Details

Sample Return Vehicle	Cis-lunar Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar space • Capability to actively rendezvous with Cis-lunar spacecraft • Capability to autonomously dock to Cis-lunar spacecraft transfer airlock	• Sample transfer airlock • Passive docking system 

Transfer

- IVA via docking/transfer lock



1. Active SRV rendezvous with Cis-lunar spacecraft

2. Active SRV docks with passive Cis-lunar spacecraft

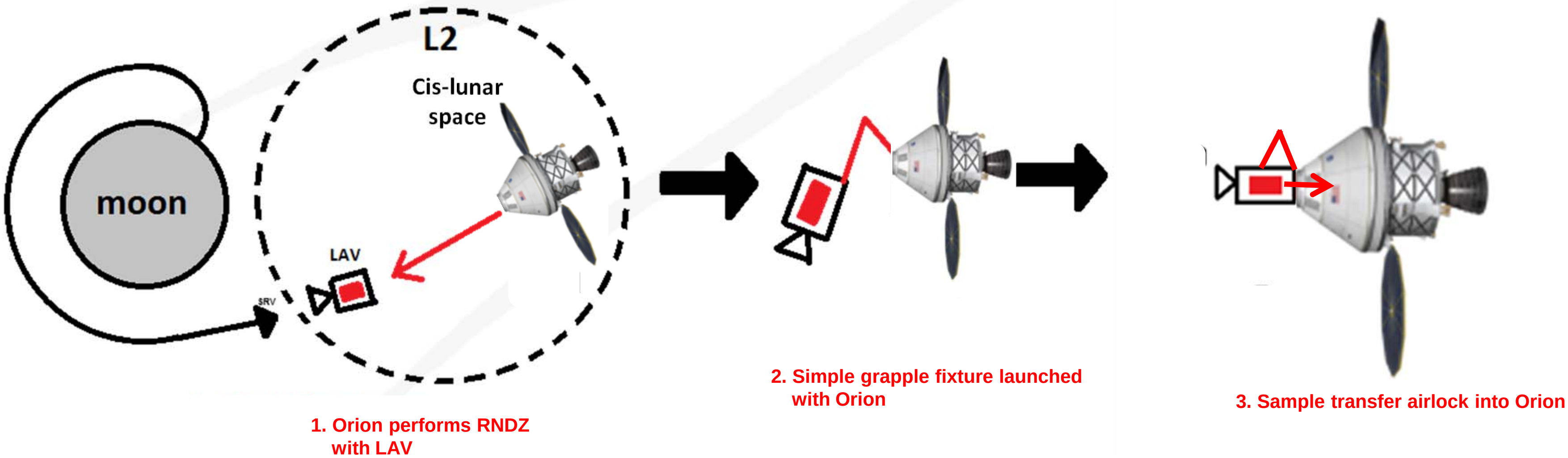
3. Sample transfer through transfer lock

Option F Details

Sample Return Vehicle	Orion Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar space • Designed for grapple and transfer lock berthing	• Active RNDZ • Grapple mechanism • Sample Transfer Airlock

Transfer

- Active Orion rendezvous with SRV
- Grapple and berth LAV to Orion sample transfer lock

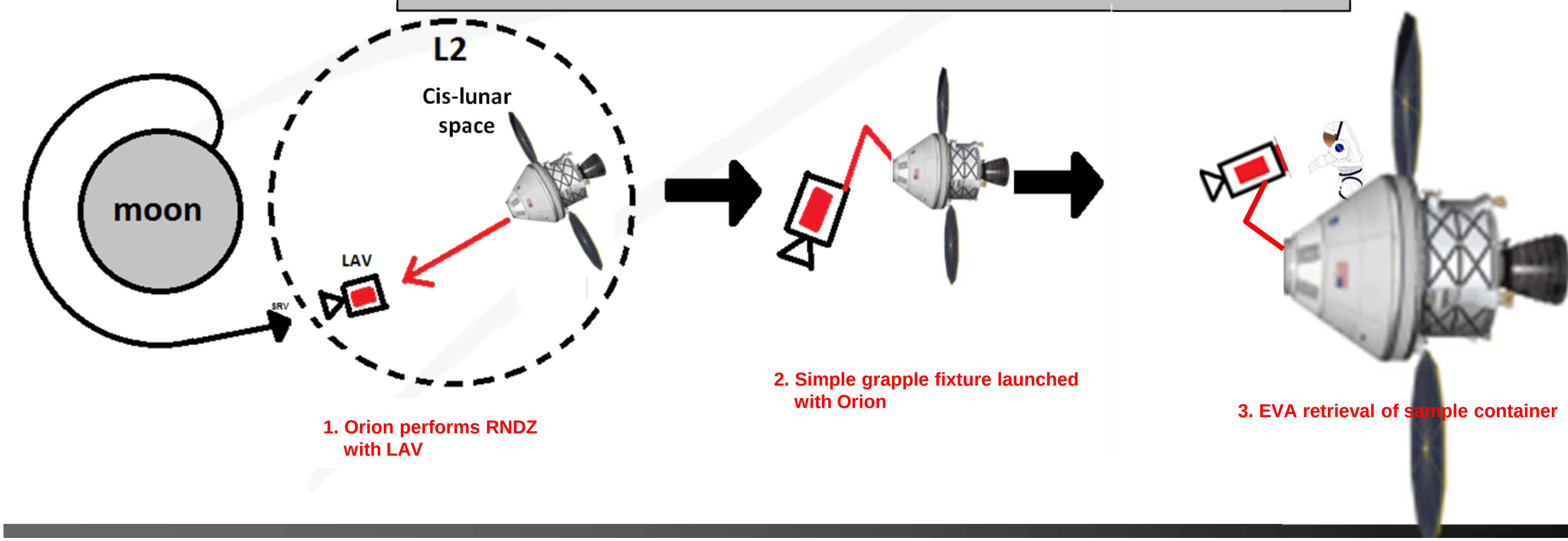


Option G Details

Sample Return Vehicle	Orion Spacecraft
• Maintains stable orbit and attitude upon reaching Cis-lunar spce • Sample container designed for EVA grapple	• Active RNDZ • EVA

Transfer

- Via EVA hatch



1. Orion performs RNDZ with LAV

2. Simple grapple fixture launched with Orion

3. EVA retrieval of sample container

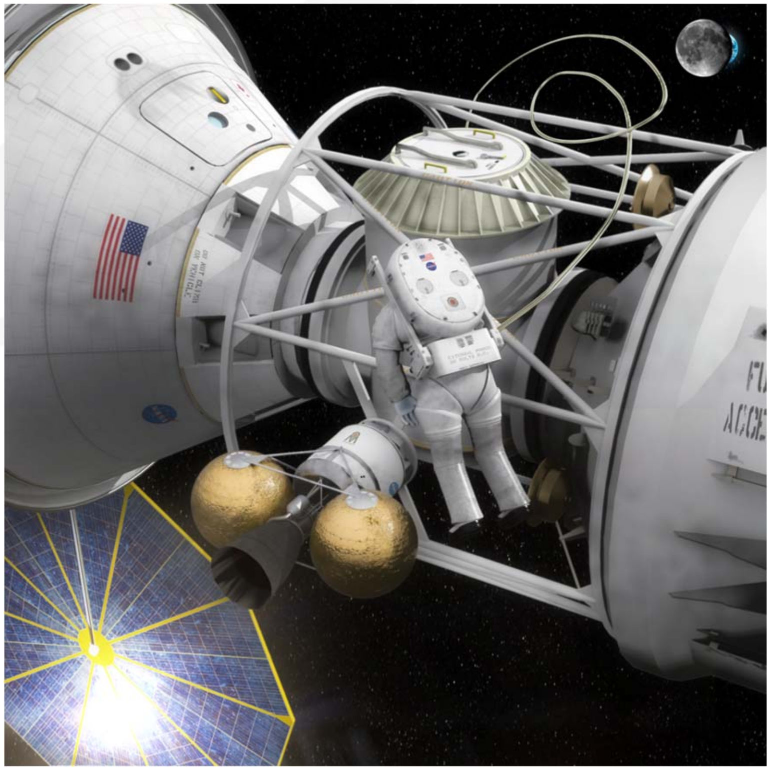
Assessment of Lunar Sample Return Options

- **Each option can be evaluated by multiple metrics, including:**
  - Mass impact to the Cis-lunar spacecraft
  - Mass impact to the Lunar Ascent Vehicle
  - Mass impact to Orion
  - Extensibility to other sample return missions (asteroids, Mars)
  - Extensible functionality that can be used for other types of missions
  - Technology readiness level
  - Risk to crew
  - Risk to mission
  - Cost
  - “WOW” factor

	Option A *Orion Chases SRV; EVA Retrieval*	**Option B** *Robonaut RNDZ w/SRV; Returns OS to Sample Transfer Airlock*	**Option C** *Active GWSC grapples SRV; “Hatch” EVA transfer*	**Option D** *Active SRV captured by GWSC; OS to Sample Transfer A/L*	**Option E** *Active SRV Docks to GWSC; IVA Sample Transfer*
“Balance” of functional split between HEOMD and SMD	Minimal functional SRV; Orion chase, RNDZ and EVA retrieval	Minimal functional SRV; GWSC chase and RNDZ; Robonaut retrieval	Minimal functional SRV; GWSC chase and RNDZ ; node hatch EVA retrieval	Active SRV chase and RNDZ; GWSC robotic arm retrieval to sample A/L	Active SRV chase, RNDZ and docking; GWSC docking/sample lock
Mass impact to GWSC					
Power, thermal impacts to GWSC					
Mass impact to SRV					
Power, thermal impacts to SRV					
Mass impact to Orion					
Extensibility to volatile sample return					
Extensibility to asteroid sample return (single kgs sample size)					
Extensibility to Mars sample return					
Extensible functionality (e.g., EVA can be used for other purposes)					
Overall TRL					
Risk to Crew					
Risk to Mission					
Wow Factor					

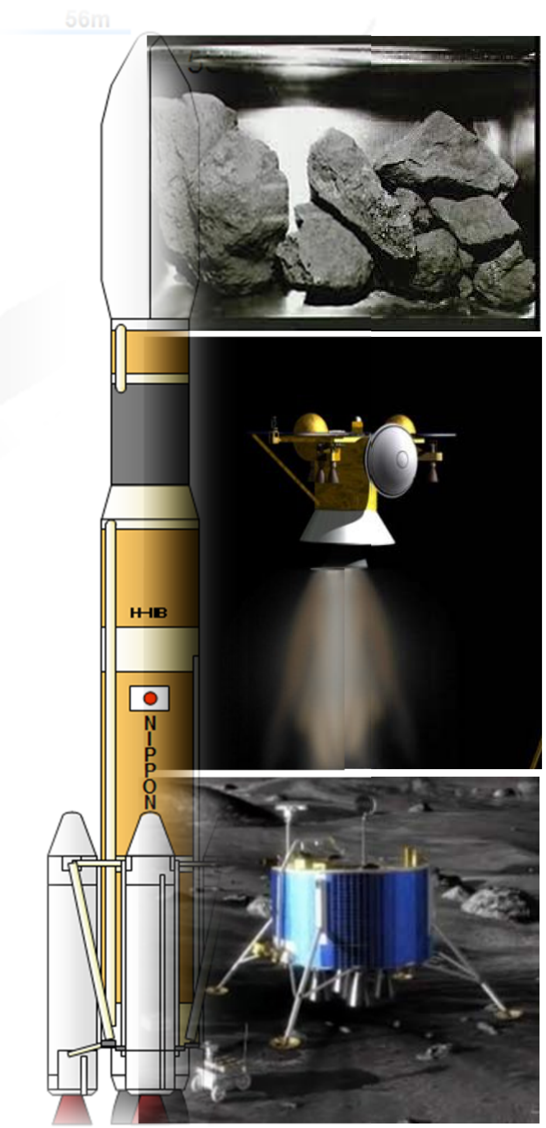
Lunar Sample Return – Initial Observations

- There is no "optimal" solution – for a successful lunar sample return (LSR) mission, the functions/complexity of rendezvous, "grappling" and transferring the sample to the pressurized environment must ultimately be assigned to one of three elements: the Cis-lunar spacecraft, Orion, or the Lunar sample Ascent Vehicle (LAV)
- If MULTIPLE sample return missions are envisioned, assigning this functionality ONCE to a reusable element will be more efficient than repeating it on multiple single-use elements
- Humans in the loop (EVA retrieval) increase the probability of mission success, but may be incompatible with planetary protection-constrained sample return missions
- Other options exist that combine elements of the seven scenarios presented



Lunar Sample Return Spacecraft

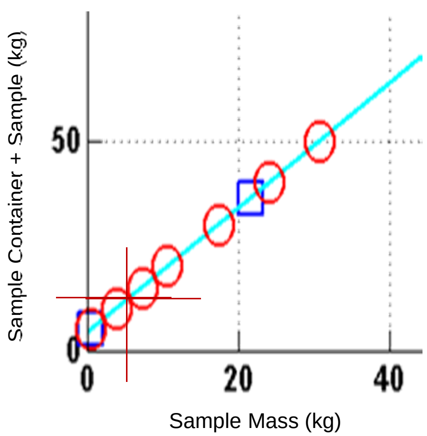
- **The mass of sample to be returned, and how those samples are separated and conditioned determines the mass of the Sample Container**
- **The mass of the Sample Container, the sample retrieval orbit, and the functionality needed for rendezvous and capture determines the mass of the Ascent Vehicle**
- **The mass of the Ascent Vehicle and the sample collection system (rovers, arms, etc.) determines the mass of the landing system**
- **The availability of a launch Vehicle to inject the mass of the lander will determine the maximum mass of the landing system, Ascent Vehicle, sample collection system, and, ultimately, the mass of returned samples**

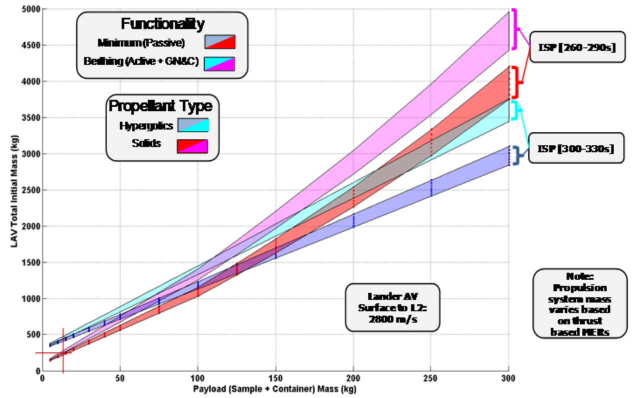


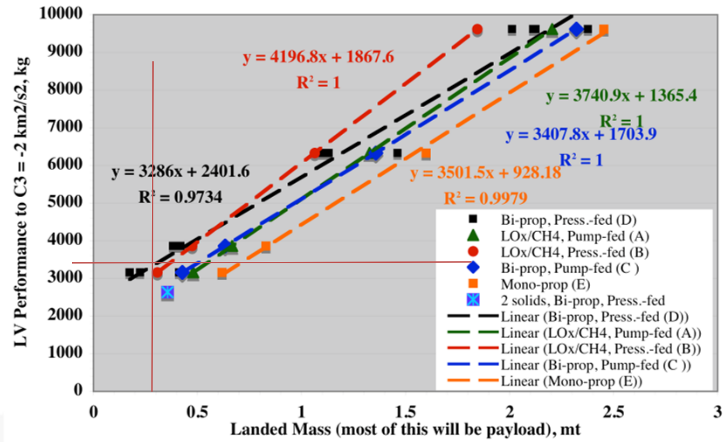
Lunar Sample Return Trade Tree

Type of Sample Return Mission	Non-volatile/Geological	Volatiles			
Transportation — ETO:	EELV	SLS/Commercial	International		
TLI:	Existing US	New Chem US	SEP		
LOI:	Re-light US	dedicated LOI stage	Add capability to descent-landing stage		
Intermediate Staging Location	L-point	HLO	LLO	None -LSR direct to surface	
Descent/Landing	Single stage chem	multi-stage solid/chem			
Lander reusability	Yes/some	none			
Surface Mission Duration	Hours	Lunar Daylight	Thru lunar night(s)		
Sample acquisition method	Lander mounted (robotic arms/drills)	tethered mobility	independent mobility		
Sample mass	<1kg	1-5 kg	5 kg+		
Sample segregation	Individually sealed samples	physically separated samples	no sample segregation		
Surface/ascent sample environment	actively conditioned	passively conditioned	unconditioned		
Additional surface science	Science conducted during sampling	Science continuing after sample departure	none		
Ascent/TEI propulsion	Solid rocket	solid-chemical	chemical	chemical-SEP	
Intermediate return orbit	L-point	HLO	LLO	none	
Return mode	Direct return to Earth	Rendezvous with a separate sample return spacecraft			
Rendezvous return mode:					
Post-ascent spacecraft	unguided-passive	active comm only	active comm and attitude		
Rendezvous /capture technique	simplified physical capture	manual capture-berthing	autonomous docking	none	
Sample transfer technique	EVA-manual	transfer airlock	none (external stow?)		
Direct return mode:					
Post-TEI spacecraft	unguided-passive	active comm only	comm, attitude control and propulsion		
Earth encounter mode	direct entry	capture/Earth orbit rendezvous			
Return/entry sample environment	continuous active conditioned	passive conditioned	unconditioned		

Lunar Sample Return to L2 Spacecraft Sizing Example







5 kg sample mass

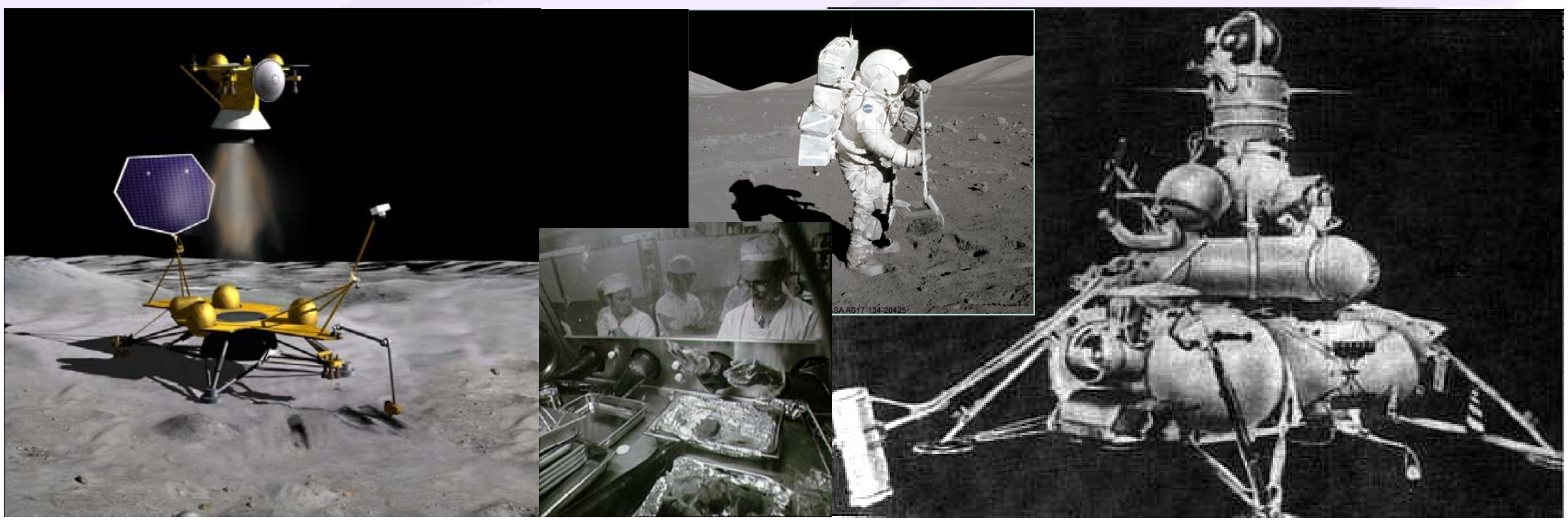
→ 12.4 kg Sample Container (+ sample) mass

12.4 kg Sample Container mass + hypergol ascent propulsion to L2

→ 250 kg Ascent Stage mass

250 kg Ascent Stage mass + 100 kg sample collection system and other science + biprop landing stage

→3200 kg Lander mass/ injected mass



Extensibility to Mars and Asteroid Sample Returns

- **Mars sample return**
  - Sample retrieved in cis-lunar space
  - Sample rendezvous and capture techniques similar to those for lunar mission
  - Planetary protection protocols must be followed
  - Sample likely placed into second container for transport back to Earth
  - Sample returned to Earth in the Orion spacecraft
- **Asteroid sample return**
  - Two scenarios
    - Robotic spacecraft brings sample from asteroid to Cis-lunar space
      - Sample retrieved in manner similar to lunar samples
    - Asteroid is transported to Cis-lunar spacevia an in-space tug
      - Surface samples retrieved via EVA and EVR
  - Planetary protocols may or may not be necessary
  - Sample returned to Earth in the Orion spacecraft