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Lunar – reDirected Orbiting Resource Asteroid Demonstration and Operation

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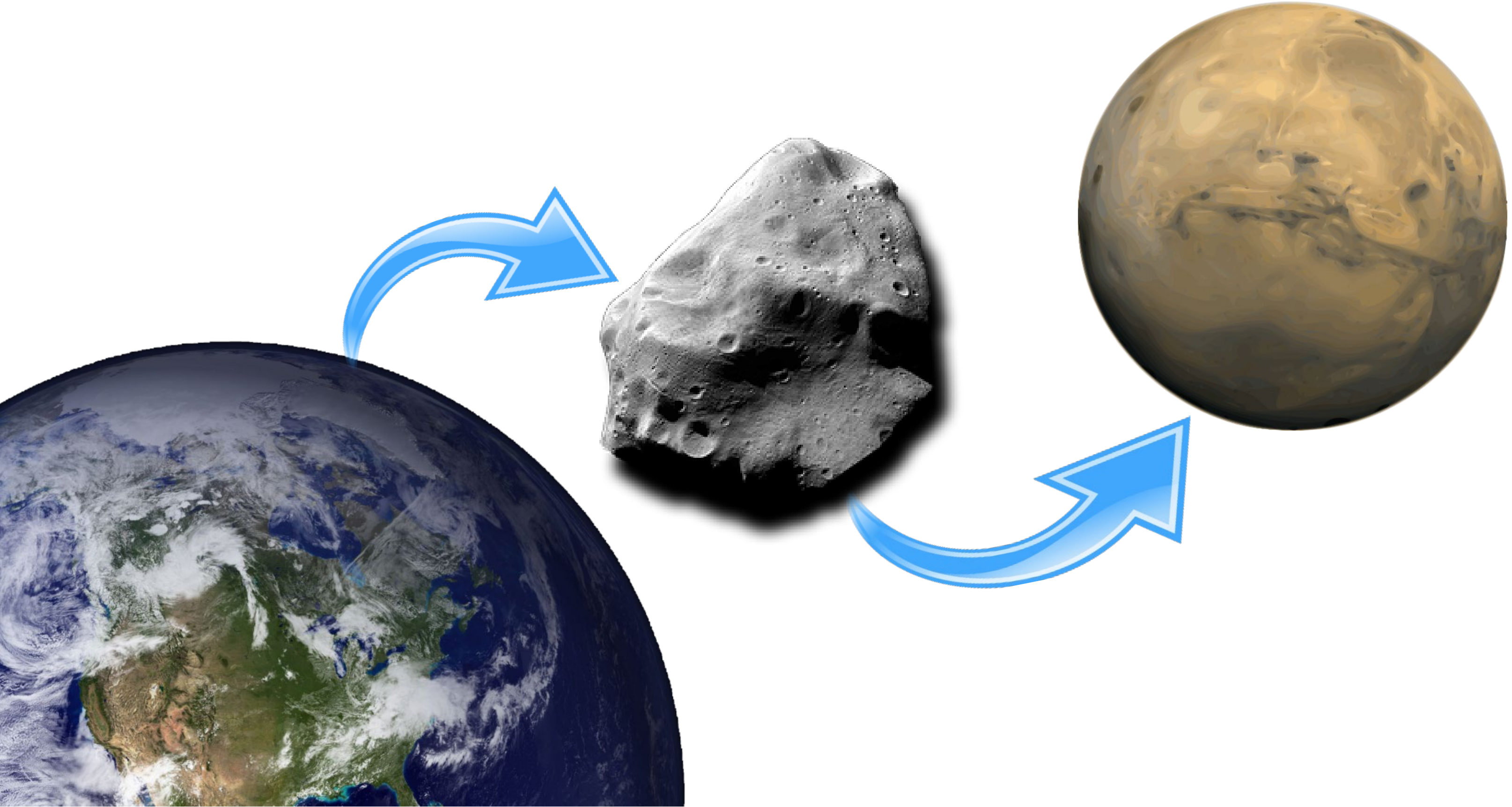
27 March 2015

The Big Picture

Project Explorer brings astronauts to the lunar orbiting ARM asteroid in 2025 to characterize, extract, and utilize its resources in order to demonstrate the potential benefits for humanity and future exploration missions.



Executive Summary

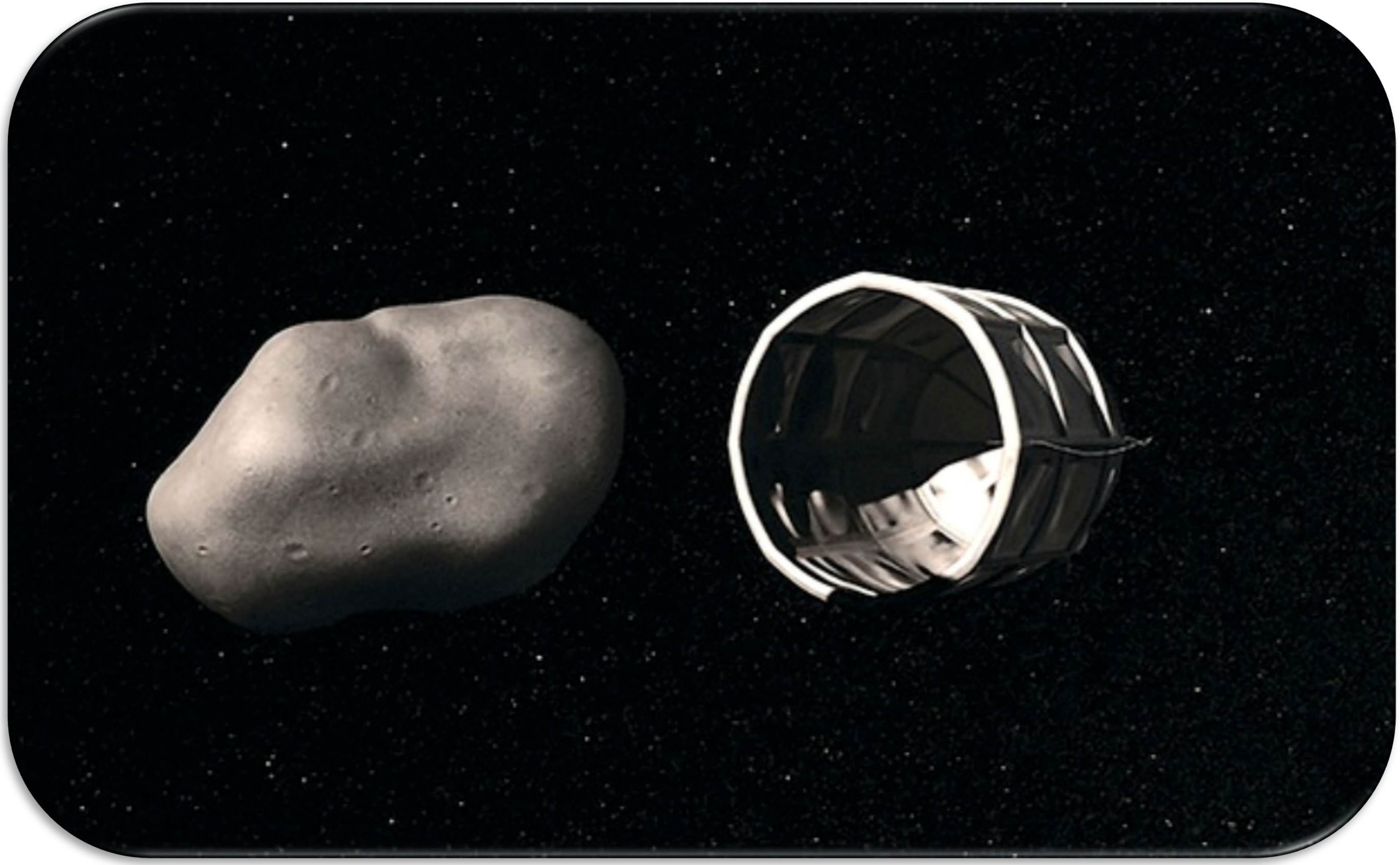
- Two rockets: One for cargo and one for crew
- The Eureka science module launches in August 2024 and heads to the asteroid
- A 3-person crew launches in February/March 2025
- 8.5 day prograde lunar flyby trajectory to reach the asteroid
- 22 days of on-asteroid operations
  - Characterization of the asteroid and its environment
  - Resource extraction, processing, and utilization
  - Public outreach
- 8.5 day trajectory to return to earth
- Abort options drive mass and schedule design limits
- Uses Orion and SLS architecture
- $3.1 billion projected cost ($1.8 Billion without launch costs)

Presentation Flow

1. Build the foundation
2. Make it flexible
3. Make it creative
4. Make it fun

Table of Contents

Introduction: Step One



Now What?

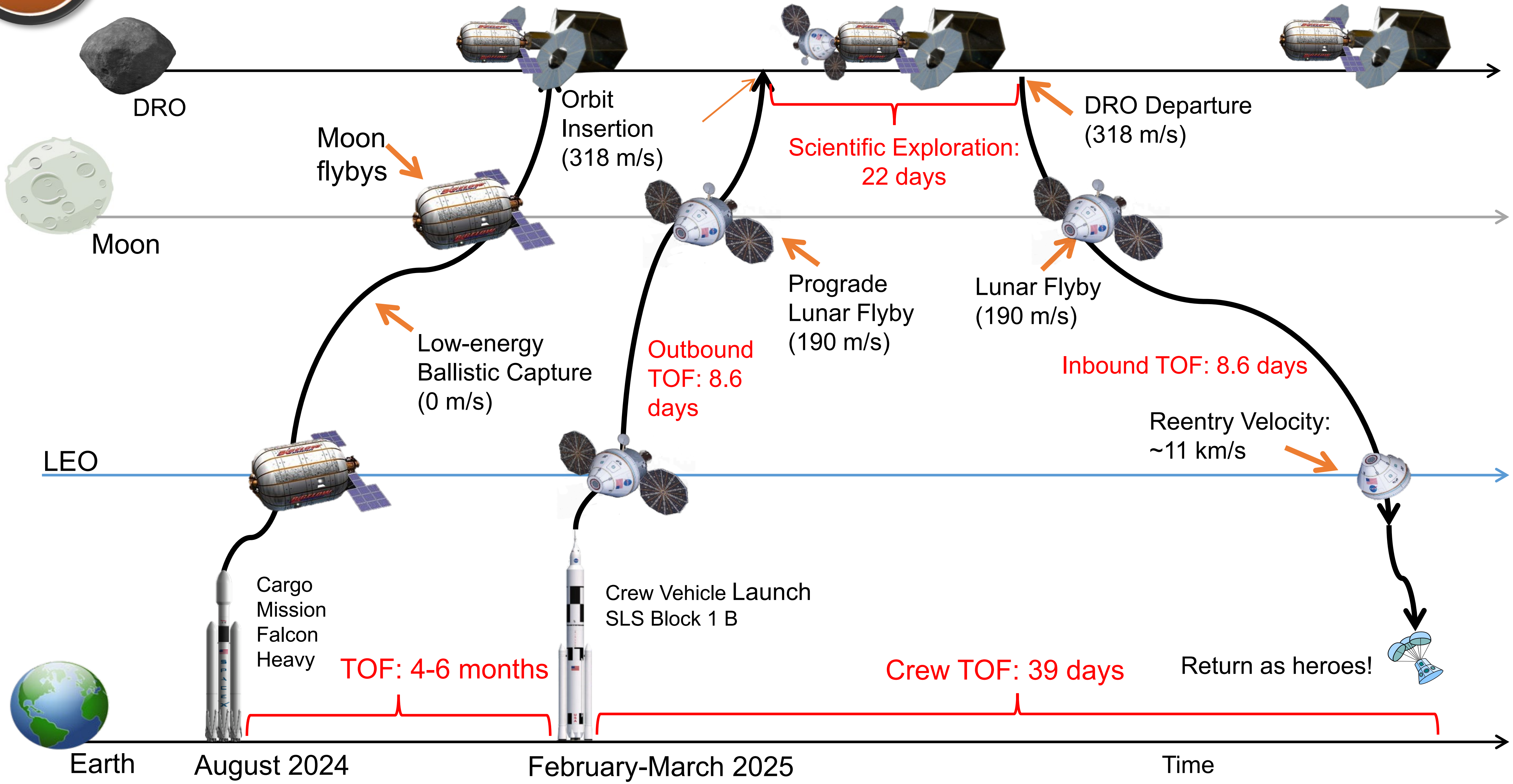
Critical Ground Rules and Assumptions

- In place by 2024
- Class “C” Asteroid
- 500 metric tons
- Design for A or B
- ARM Power can be used

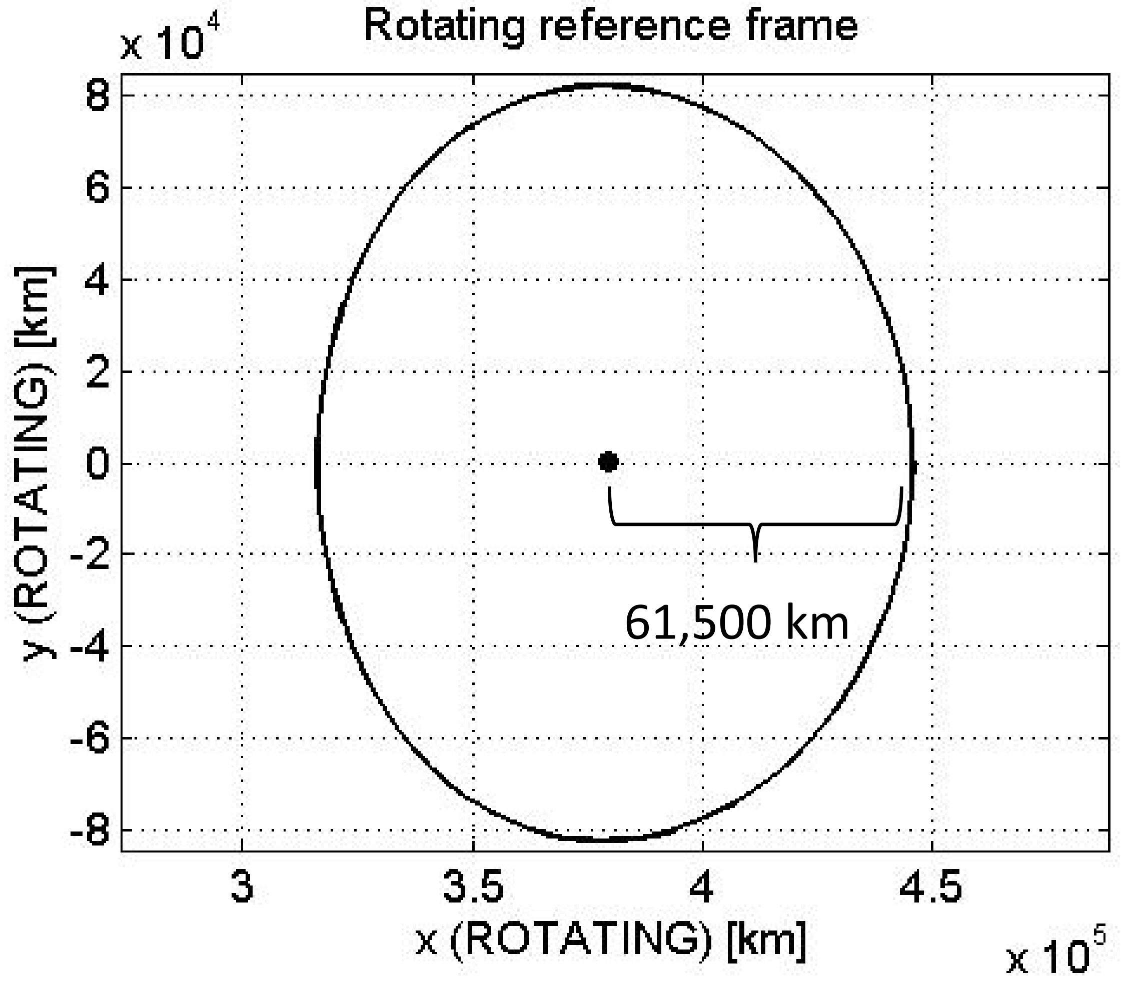
- Use SLS and Orion for Crew
- Block 1, 1B Available
- Block 2 Maybe Not
- 2+ Astronauts
- TRL 8+
- Standard NASA Procedures

- International Cooperation
- Public Outreach is Critical
- Planetary Protection Mandate

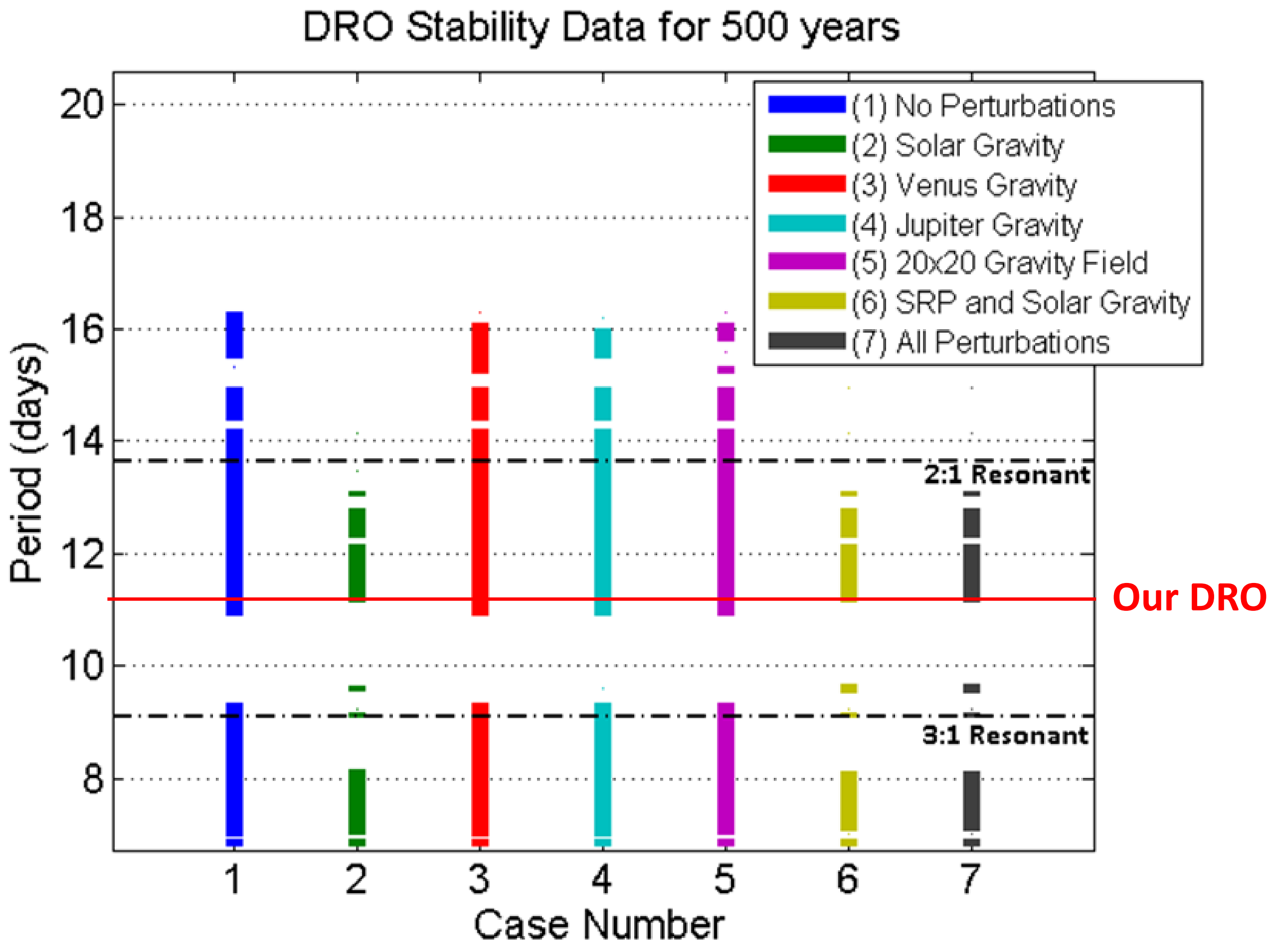
Mission Overview



Trajectory Planning: The Asteroid's Orbit



Period of DRO = 11+ days



Bezrouk, Collin, and Jeffrey Parker. "Long Duration Stability of Distant Retrograde Orbits." AAS (2014): n. pag. Web.

Launch strategy

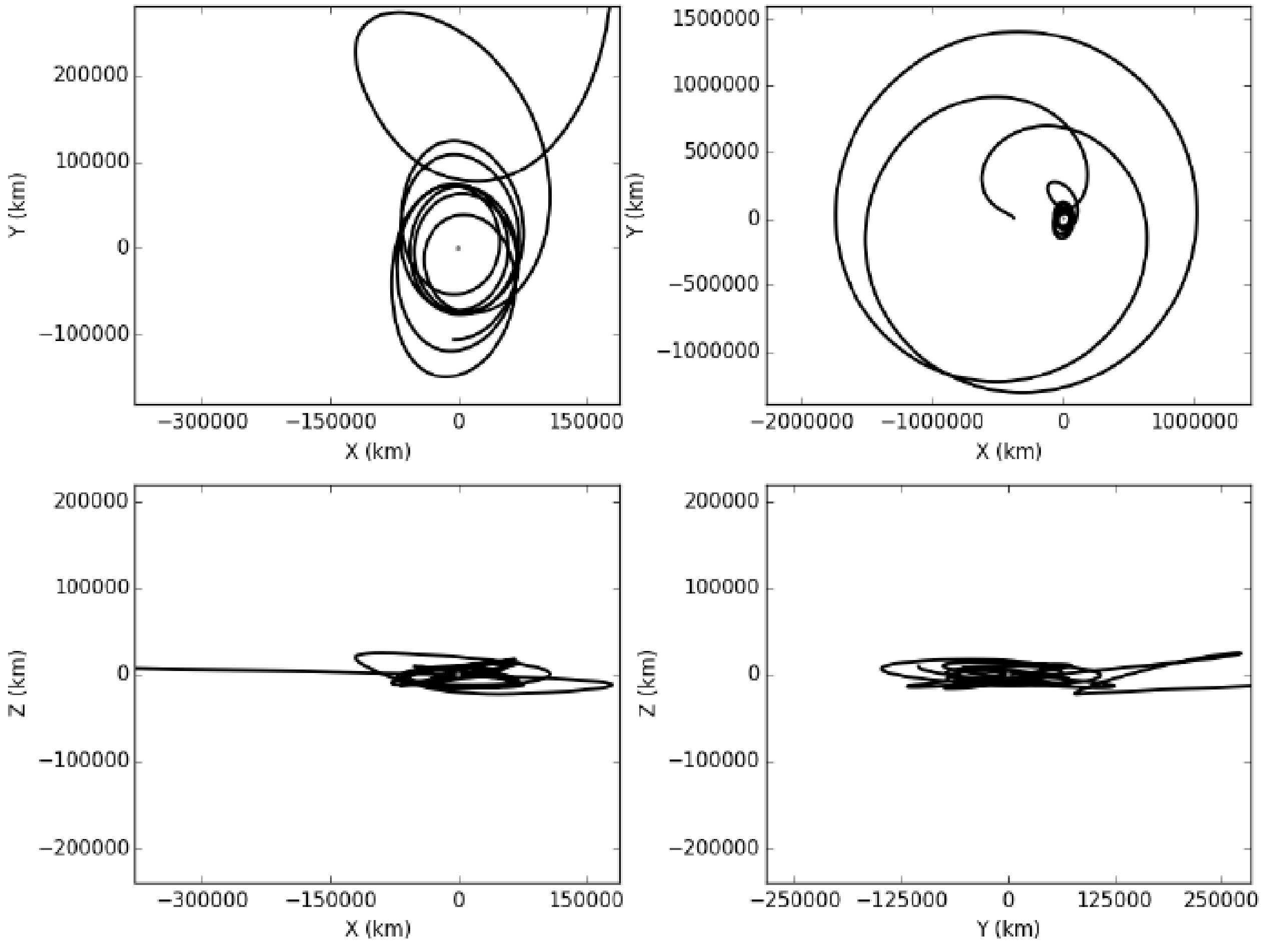
2 Launches

SLS Launch Sequence

Rocket	Mass to TLI (t)	Payload	Payload mass (t)	Launch date
Falcon Heavy	≤ 18	Eureka	17.2	August 2024
SLS Block 1B	~ 47	Orion	36	February 20, 2025

- SLS may only be able to launch once per year; need SLS for Orion launch
- Baseline: Launch 1 - Falcon Heavy, Launch 2 - Orion
- SLS Block 2 can be used if available (2024?) -> Only one launch needed

Transit: Eureka Trajectory



Low-Energy Ballistic Capture

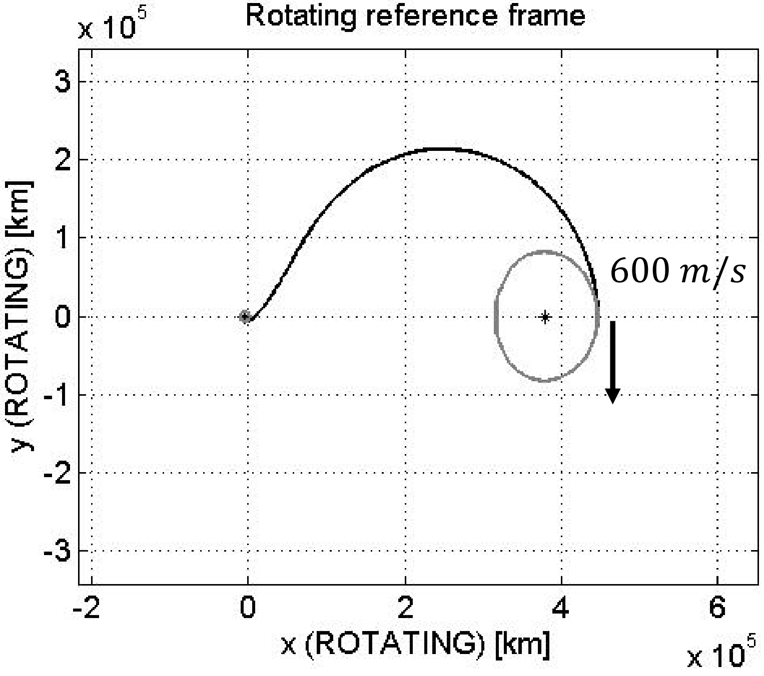
Maneuvers for Outbound Trajectory	Time since launch [mo.]	Δv [m/s]
Launch "cleanup"	~ 0	15
Rendezvous/Docking	4-6	15

$$\Delta V_{tot} = 30\ m/s$$

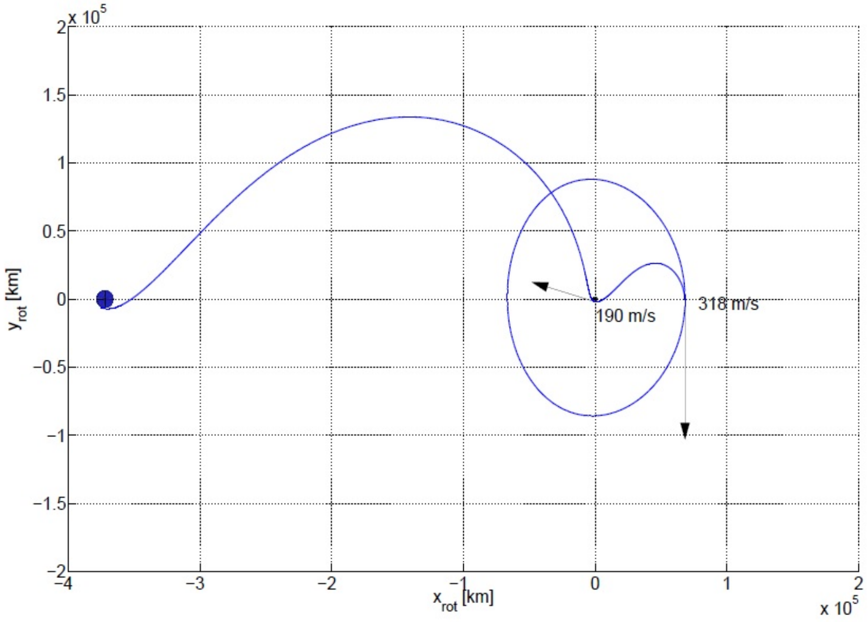
SEP was also considered but not selected because of additional system complexity

Herman, Jonathan F.C., and Jefferey S. Parker. "Low-Energy, Low-Thrust Transfers Between Earth and Distant Retrograde Orbits about the Moon." Annual AAS Guidance & Control Conference (2015): n. pag. Web.

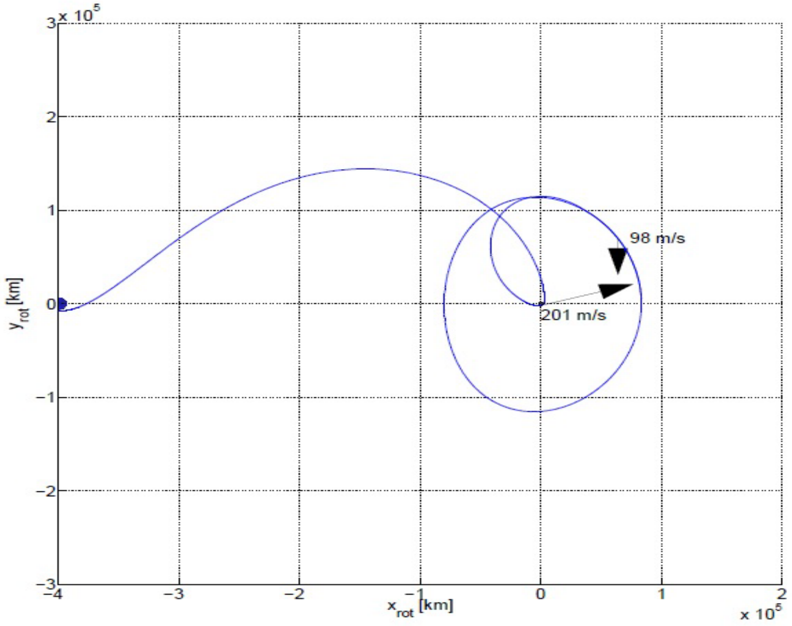
Transit: Crew Trajectory Options



Direct Transfer



Prograde Powered Lunar Gravity Assist

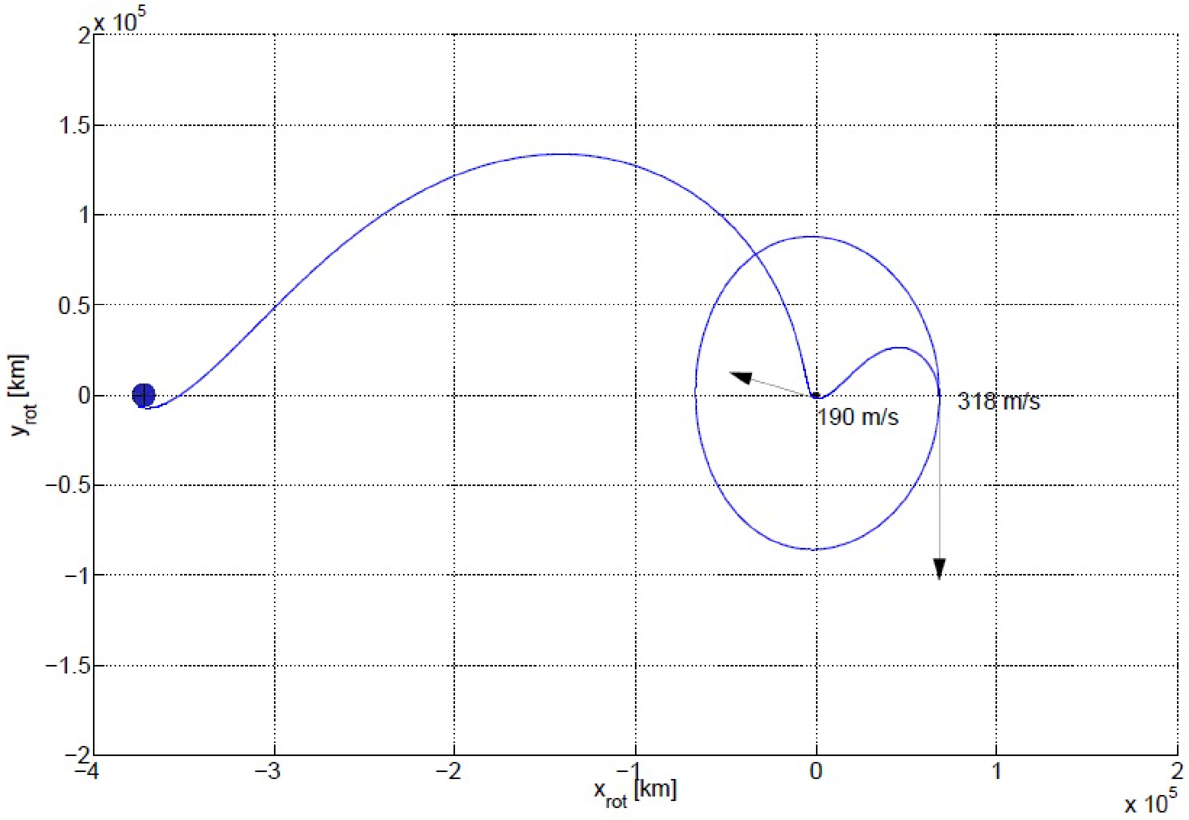


Retrograde Powered Gravity Assist

Outbound/Inbound Option	Δv [m/s] (one-way)	TOF [days]
Direct Transfer	600	5.9
Prograde Powered Lunar Gravity Assist	508	8.6
Retrograde Powered Lunar Gravity Assist	299	13.5

Landgraf M., Duering M., and Renk F. “Mission Design Aspect of European Elements in the International Space Exploration Framework”

Transit: Crew Trajectory



Landgraf M., Duering M., and Renk F. "Mission Design Aspect of European Elements in the International Space Exploration Framework"

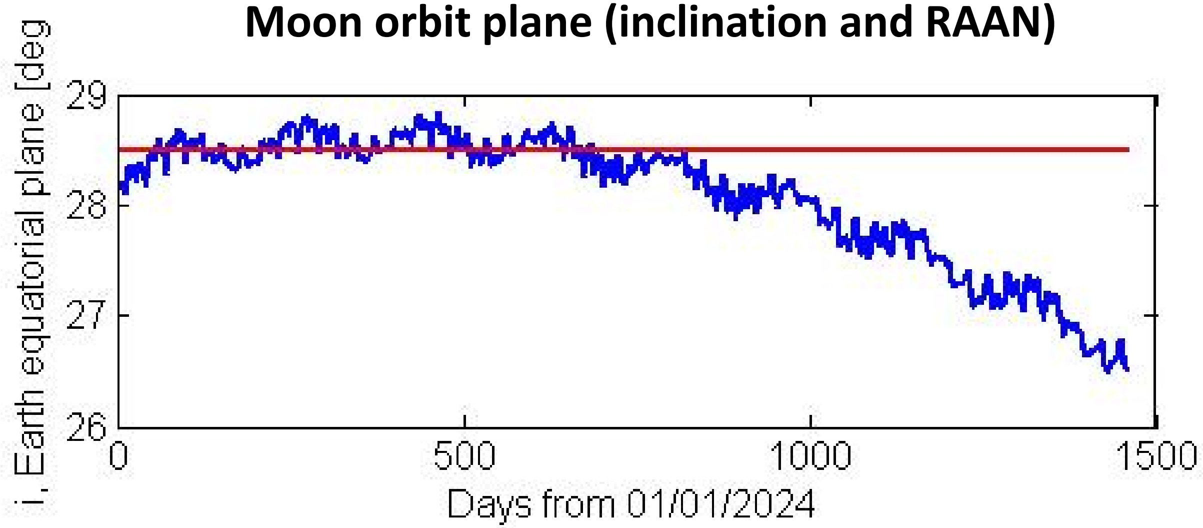
Maneuvers for Outbound Trajectory	Time since launch [days]	Δv [m/s]
Launch "cleanup"	~ 0	20
Gravity Assist	4.6	190
DRO Injection	8.6	318
Rendezvous/Docking	8.9	15

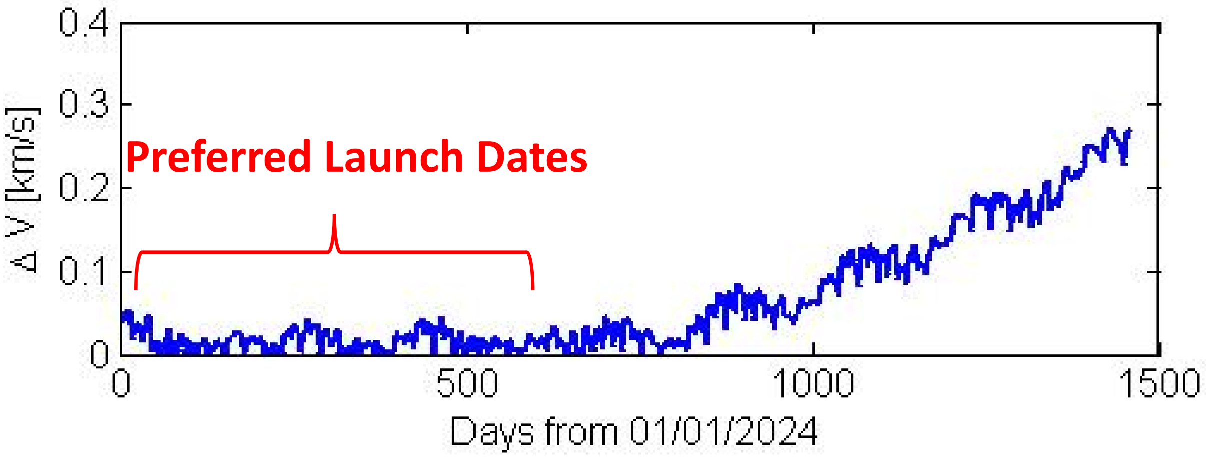
Maneuver for Inbound Trajectory	Time since launch [days]	Δv [m/s]
DRO Departure	30.6	318
Gravity Assist	34.6	190

$\Delta V_{tot} = 1051$ m/s $\quad \Delta V_{ava} = 1338$ m/s

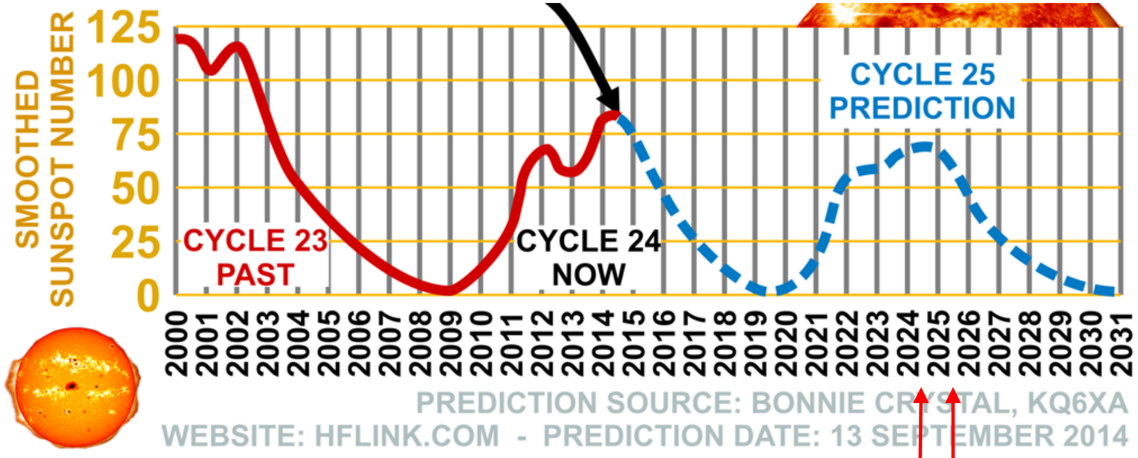
Transit: Launch Date and Time Selection

Moon orbit plane (inclination and RAAN)





RAAN: one launch opportunity per day



Cargo Launch 08/2024

Crew Launch 03/2025

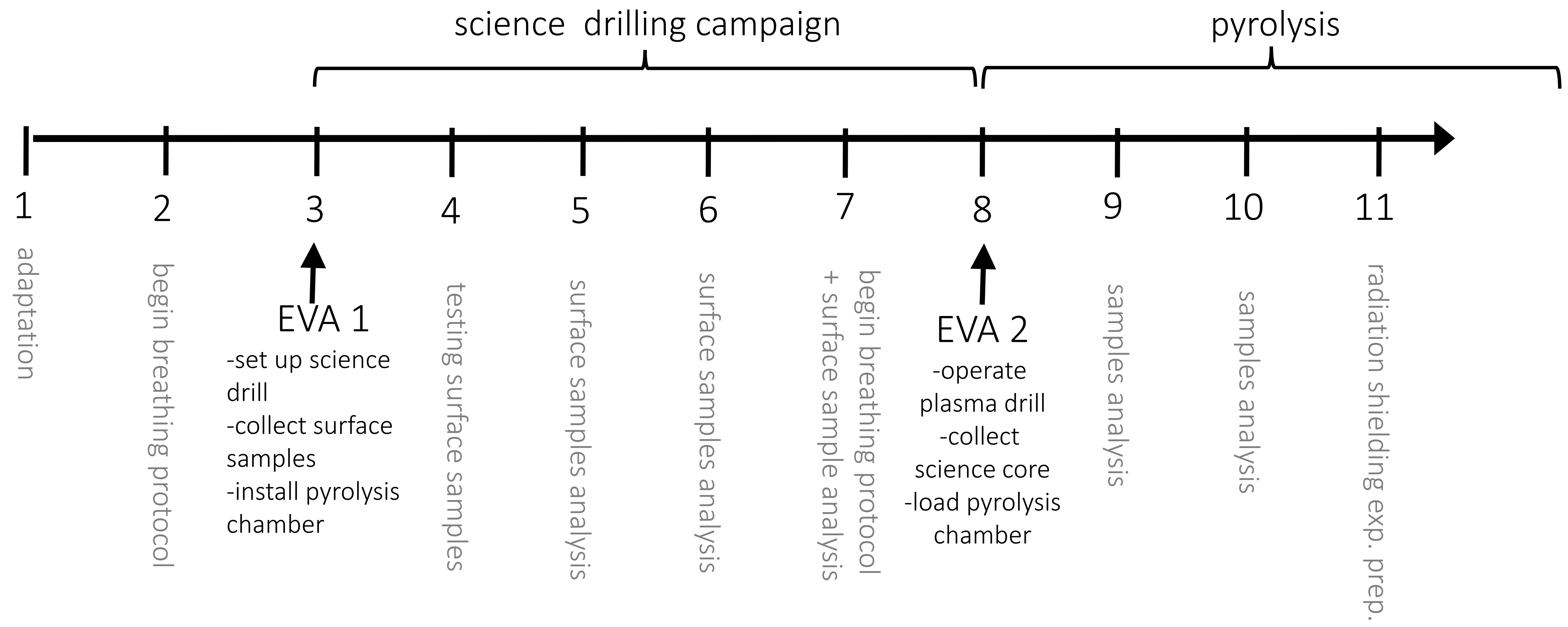
Optimal Launch Opportunity: Arriving at DRO at the lunar perigee within the above windows. (reduced time of flight and ΔV)

http://qrznow.com/wp-content/uploads/2014/09/Prediction_Solar_Cycle_-25_HFLINK-190x122.png

Science and Tech Demonstration Objectives

	Decadal Survey/Stratgic Knowledge Gap	Objectives
S1	Understanding Solar System Beginnings	Quantify composition, characterize surface processes, probe internal structure, characterize water phases
S2	Revealing Planetary Processes through Time	
S3	Searching for the Requirements for Life	Detect and identify organic compounds
T1	In-situ Excavation of Small Body Material	Excavate enough rocks for 5 kg of water
T2	Extraction of Resources from Excavated Material	Extract water, separate oxides
T3	Demonstrate Utilization of Extracted Resources	Steam rocket, H/O, sintering, radiation+thermal shielding experiment, experimental garden

Operations Plan – Days 1-11



Operations Plan – Days 12-22

experimental garden (days 16–22)

pyrolysis (days 12–15)

shielding experiments campaign (days 15–22)

- 12: radiation shielding exp. testing
- 13: samples analysis
- 14: samples analysis
- 15: EVA 3
  - -collect pyrolysis end-product
  - -sinter
  - -shielding experiment
  - -load steam rocket
  - -deploy SPHEREs
  - -outreach
- 16: water purification
  + start experimental garden
- 17: steam rocket
  + electrolysis (H/O)
- 18: oxides separation
- 19: samples analysis
- 20: samples analysis
- 21: samples analysis
  + astronaut sorbet
- 22: packing and disposal

More science on Earth:
dating, isotopes, space weathering, oxides, silicates, etc.

Science: Primary Instruments

Imaging

High-Res Camera

Microscopic Imager

Mineralogy

Active hyperspectral VISIR spectrometer

X-Ray Diffractometer

Sampling

Coring Drill

Chisel-in-a-Cup

Chemistry

Alpha Particle X-Ray

Radiation

Radiation Detectors

Structure

Density Probe

Neutron Probe

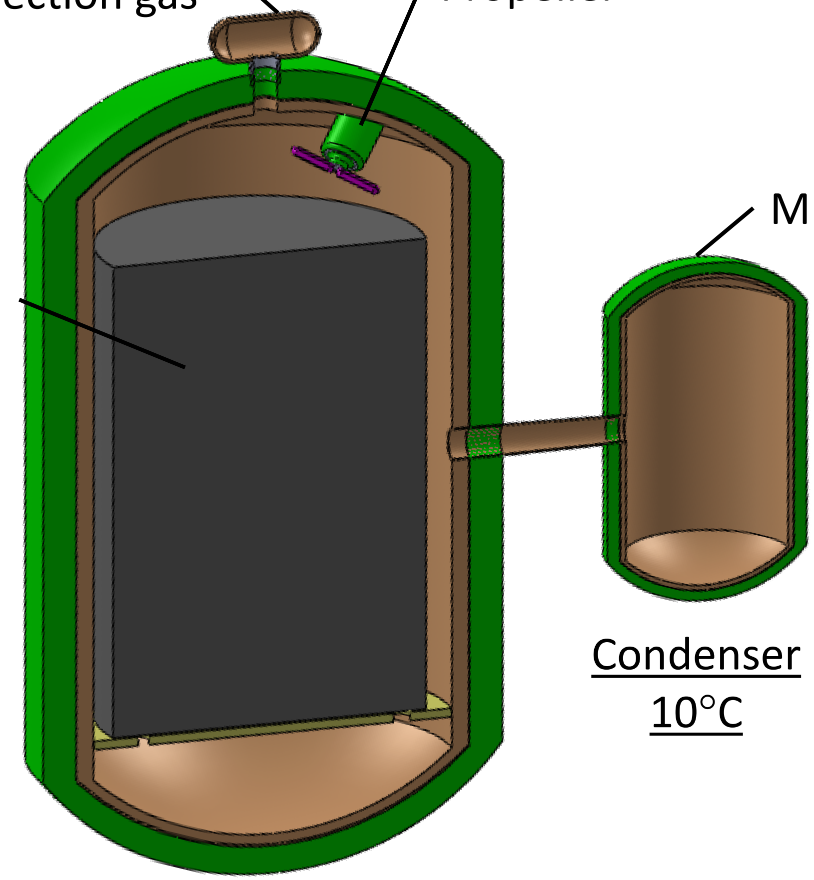
Gamma Ray Probe

Thermocouples

Organics

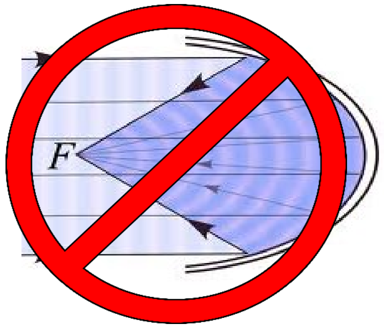
Gas Chromatography - Mass Spectrometer

ISRU: Extracting Volatiles from Ore



Max ore capacity = 250 kg
0.5 m internal diameter

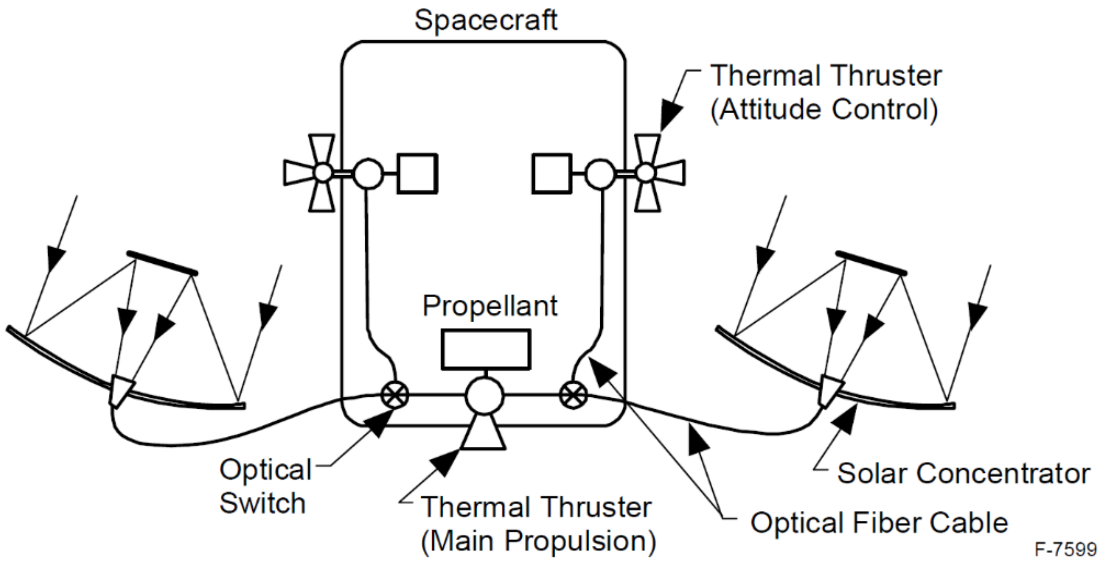
- Pressure valve opens to condenser at 1 atmosphere
  - Initially water vapor and then liquid water in container
- Heating via resistance heaters and propeller for circulation



- Minimum 5 kg water extracted
- Centrifuge then separates volatiles

Tech Demos: Steam Rocket, Radiation Shielding

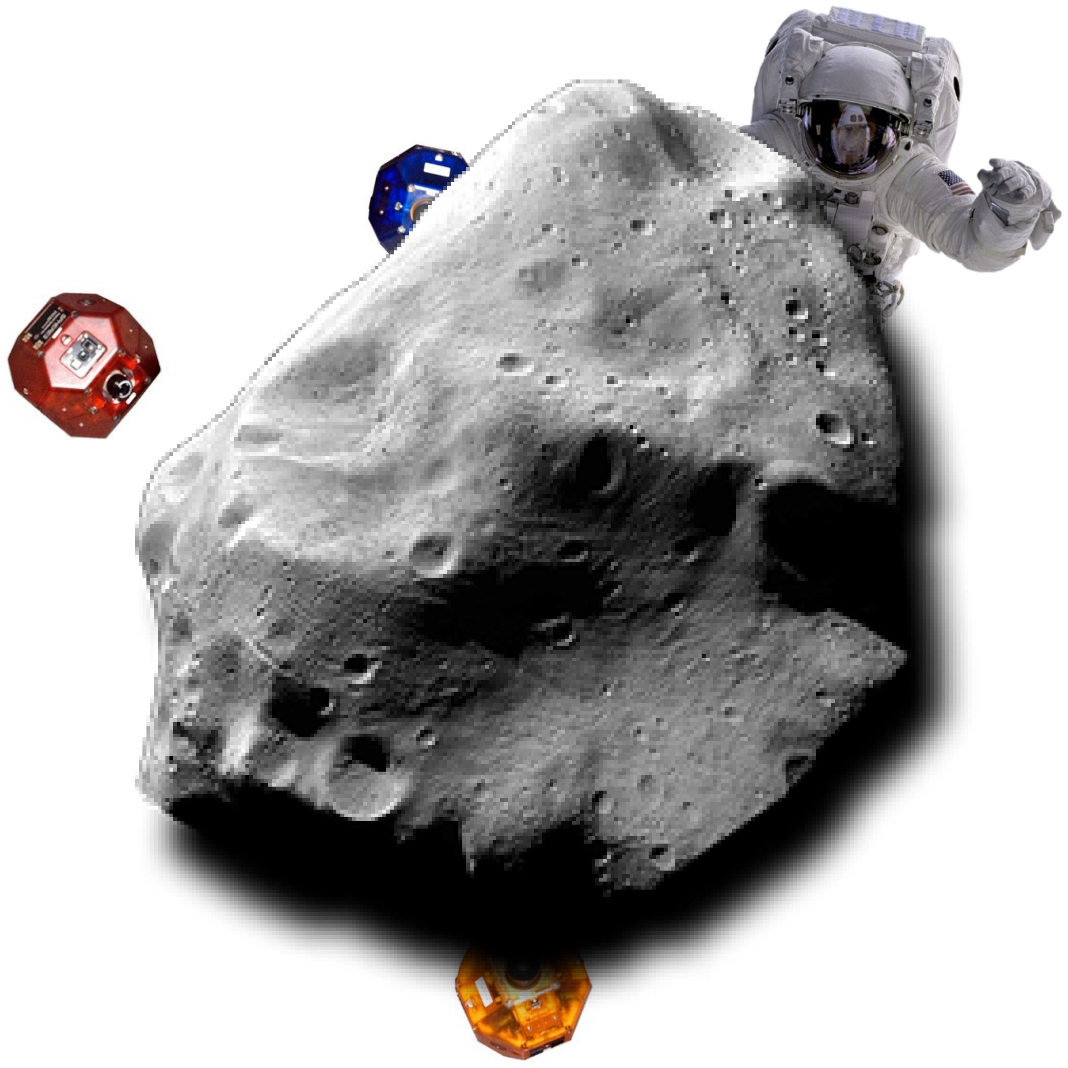
- Test 15 kg steam rocket
  - Concentrated sunlight vaporizes asteroid water → thrust
  - Low ISP (~40 sec)
- Good for on/near asteroid operations
  - Rugged, simple engine
  - Fuel easy to store as ice



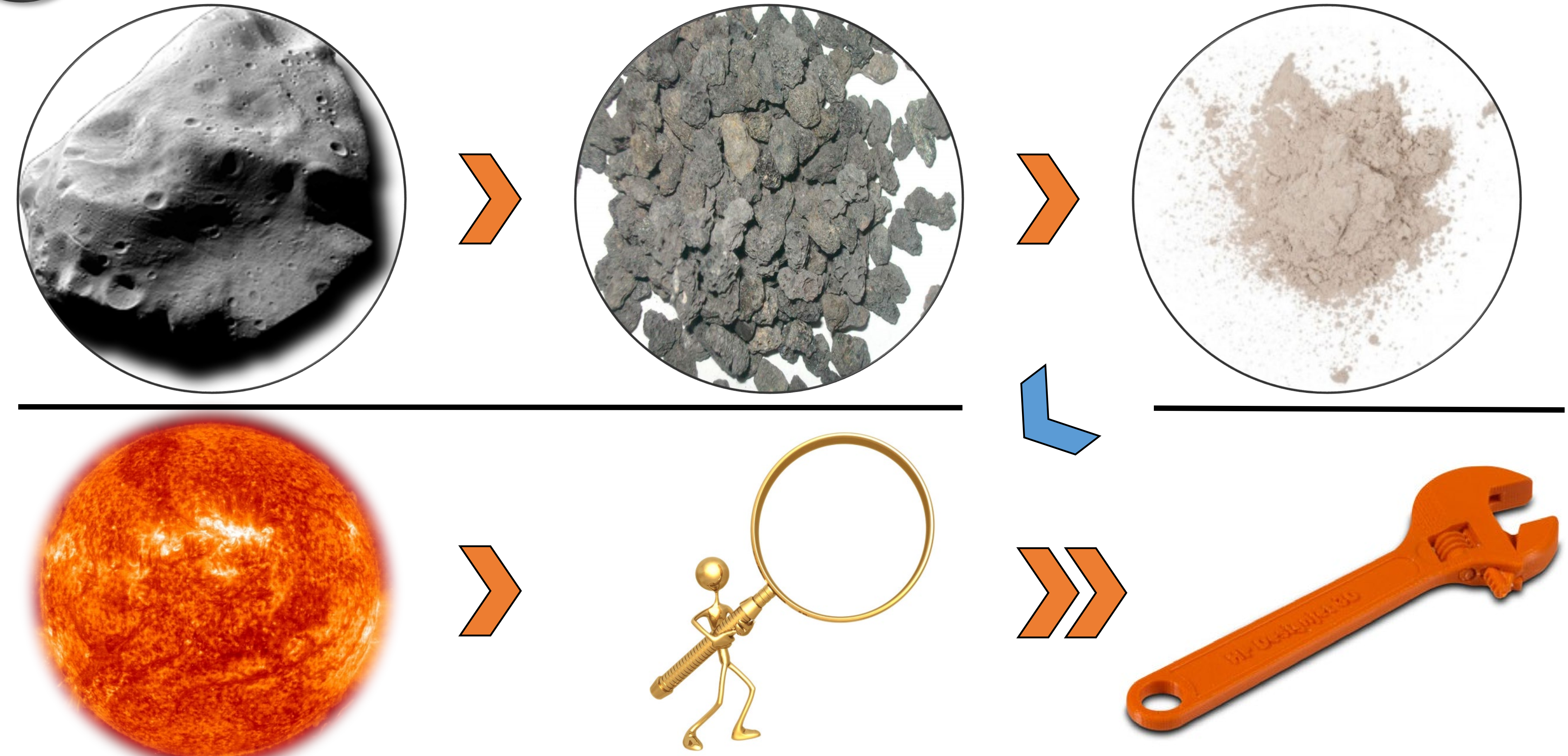
Steam Rocket (Nakamura)

Tech Demo: Semi-Autonomous Robotic Swarm

- Derived from the MIT SPHERES-project
- Allow for remote and local control
- Leave behind as “inhabitants”
- Augment situational awareness
- Increase outreach capabilities



ISRU: Solar Powered Sintering



ISRU: Plant Experiment

Adding Value: Use ARM's 50 kW Power and Eureka

50 Kilowatt Deep Space Network

Resource Depot

Moon/Mars Abort Station

Wireless Power Demo

Crew Size, Selection, Training

Selection
- 2 x scientists, 1 x engineer
- odd numbered crew to avoid decisional splits
- people of task-focused styles perform better: aptitude, personality, attitudes, experiences, communication skills

Training

-Psychological training
-Survival training
-Group building activities
-Training together

Physiological Deconditioning & Countermeasures

-Typical countermeasures for in-flight, pre-landing, post landing

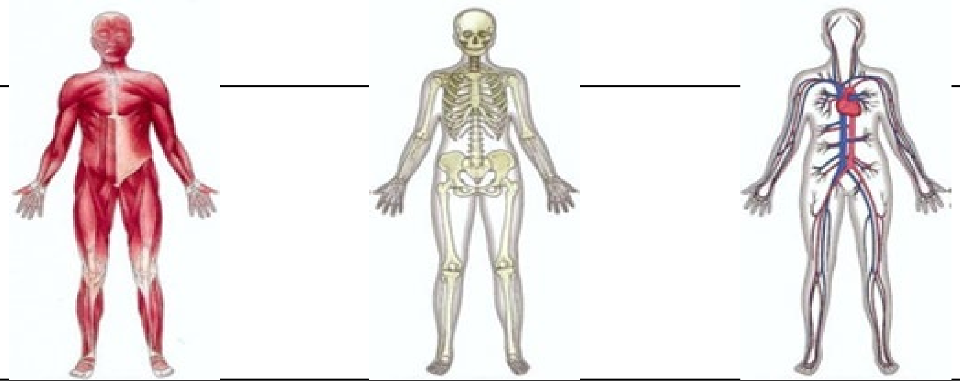
-Resistive Exercise Device: Rotary MR Damper

-current TRL level of 3, expected TRL level of 7 at TOF

-specifically developed for compact volumes

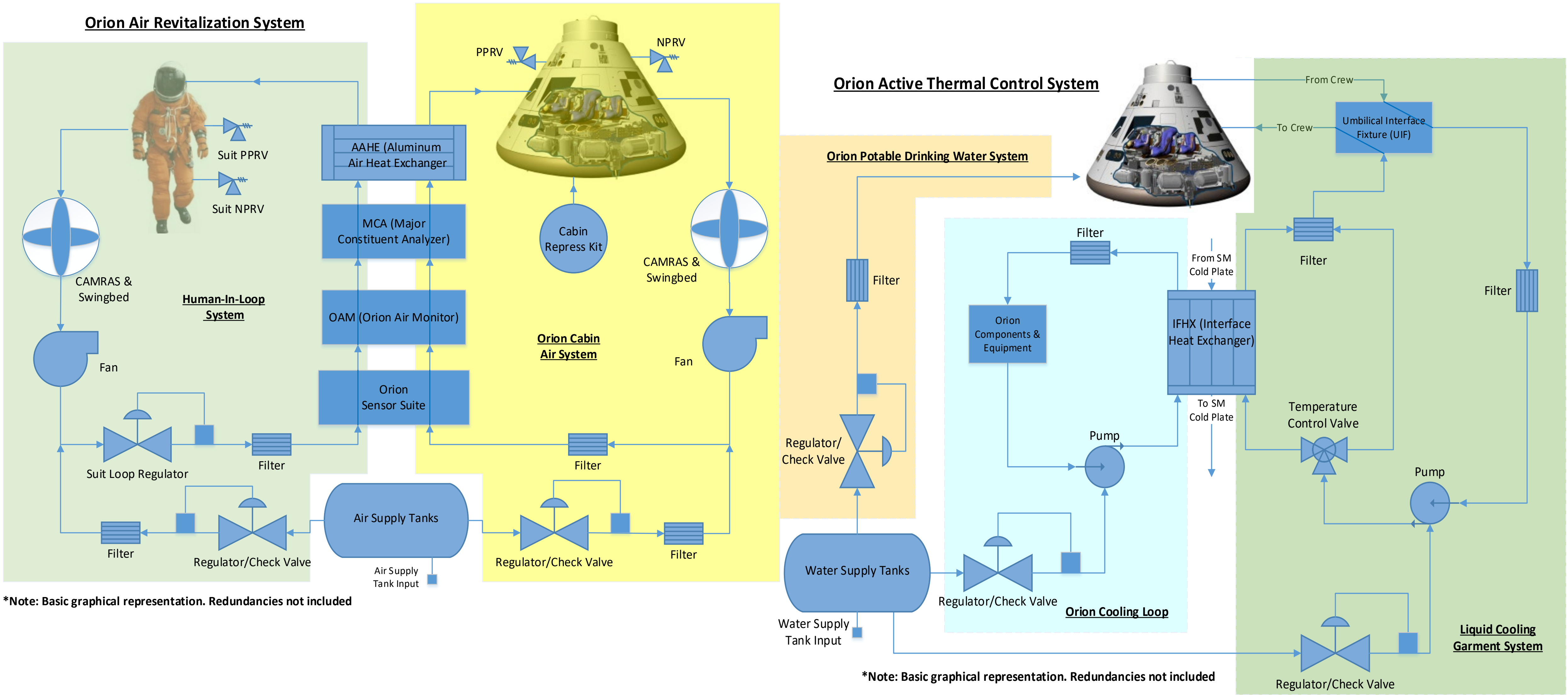
-Radiation Protection: water walls in Eureka, X-ray monitoring using GOES

-no risk of GCR / risk of SPE



-changes in HR, cephalic fluid shift, bone mass density loss, cardiovascular changes, muscle atrophy, radiation protection

ECLSS: Understanding Orion



*Note: Basic graphical representation. Redundancies not included

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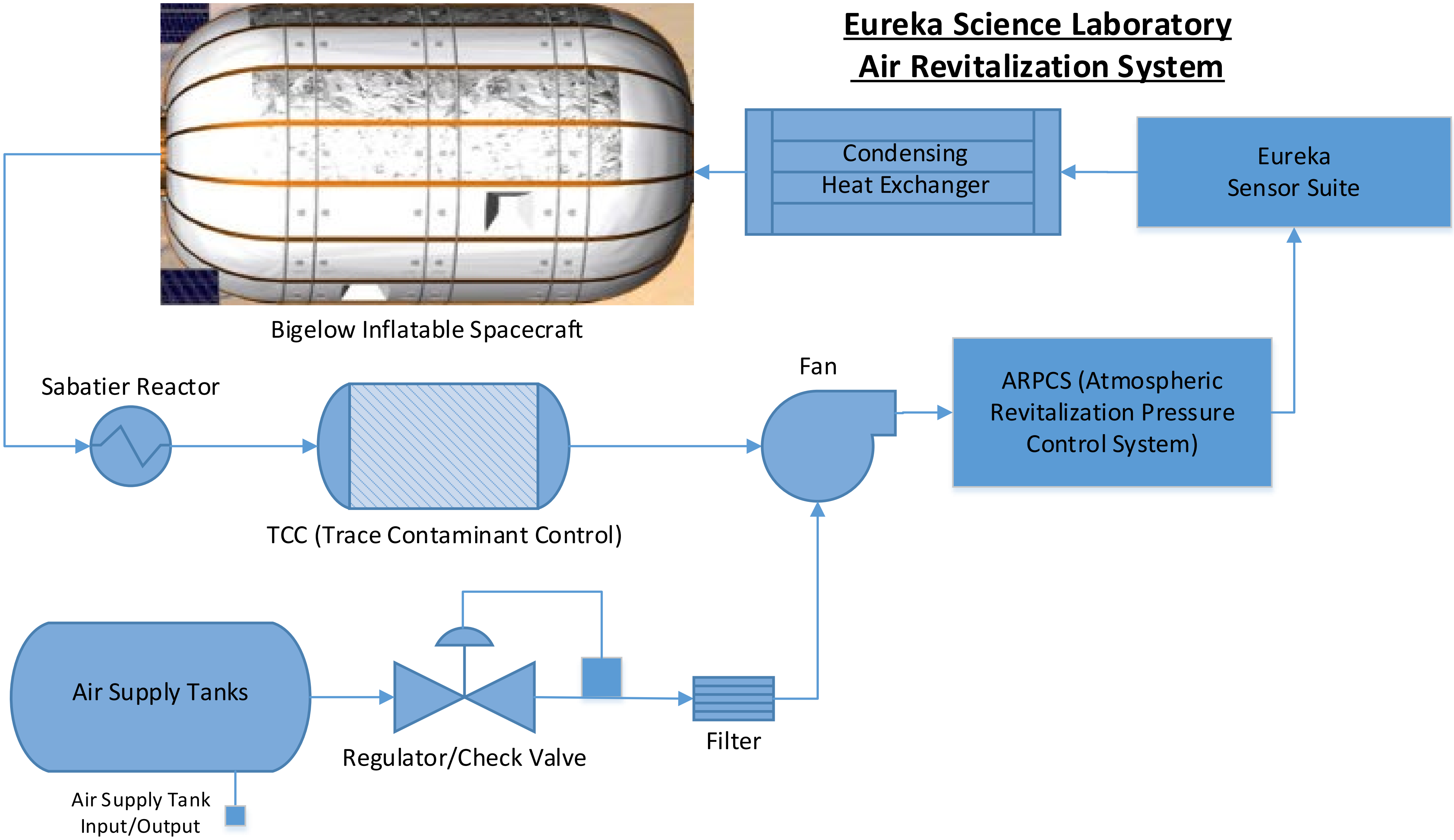
ECLSS: Building an Independent System



ECLSS: Eureka Environmental Control & Life Support Systems

Atmospheric Monitoring & Regulation

- CO2 Reduction: Sabatier (chosen over Bosch and LiOH)
- Non-regenerable O2 generation: O2 tanks
- Sensor suite for monitoring
- TCCS: charcoal sorbent bed to catalytic oxidizer
- Fire detection & suppression: JPL E-Nose

Demonstration for future ECLSS Reservoirs

Water Recovery & Purification

-Vapor Phase Catalytic Ammonia Removal (VPCAR) System

-Trades included ISS Water Recovery System & Forward Osmosis Bag

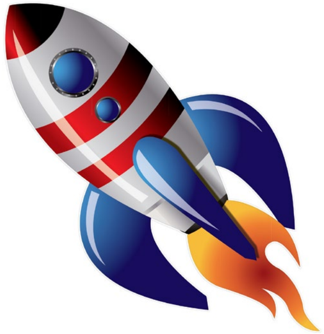
Oxygen Generation with H2 byproduct as Rocket Fuel Source

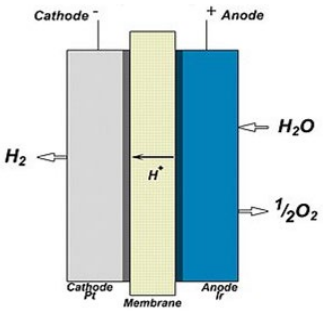
Solid Polymer Electrolyte Water Electrolysis

-scaled down electrolysis

-typical of ISS Oxygen Gen Assembly

-demo for future O_2 and H_2 reserves





ECLSS: IVA Space Suit Selection

ACES (Advanced Crew Escape Suit)		MACES (Modified ACES)
9	Current TRL	6
9	2025 TRL	8
41.7	Total Mass (kg)	16
Shuttle	Vehicle Design Fit	Orion
Vehicle Provided - Open-loop	Primary Life Support	Vehicle Provided - Closed-loop
No	EVA Capability	Yes
$180,000	Cost	Unknown (Est. $360,000)

ECLSS: EVA Space Suit Selection

EMU (Extravehicular Mobility Unit)

- **TRL Level 9: Flight Proven**
- Suit Mass: 55.3 kg
- Life Support: PLSS
- Nominal EVA Time: 8 hours
- EVA Mobility: Moderate

MACES (Modified ACES) Suit

- **TRL Level 7: Demonstrated in operational environment**
- **Suit Mass: 36 kg**
- **Life Support: PLSS 3.0**
- Nominal EVA Time: 10 hours
- Mobility: Low

Z-3 (Z-Series) Exploration Suit

- TRL Level 6: Demonstrated
- **Expected TRL Level 9 by 2022**
- Suit Mass: 65 kg
- Life Support: PLSS 3.0
- **Nominal EVA Time: 10 hours**
- **Mobility: High**
- **Future Mars Exploration Suit**

Systems Engineering: Requirements

- All of the requirements are driven by four functional objectives:

#	Functional Objective
1	Safely bring and return humans to the ARM asteroid
2	Characterize the asteroid and its environment
3	Demonstrate the feasibility of in situ resource use for long term missions
4	Involve and inspire the public

- These functional objectives have children requirements. For example:

#	Functional Objective
1	Safely bring and return humans to the ARM asteroid
1.1	Protect the crew from the aerospace environment.
1.2	Provide sufficient propulsion capability to meet the science and demonstration objectives.
1.3	Design abort options to minimize crew return delays.

Systems Engineering

Payload Budget - Orion

System	Mass [t]	Volume[m³]
Orion	10.2	
Fairing, LAS, Docking	9.5	
Service Module	16.0	
Human Factors	0.65	3
Astronauts	0.29	6
Total	0.94	9
Margin	0.2	0.2
Total + Margin	36.82	10

Total

	Mass [t]	Power [kW]
Total	51.0	47.2
Margin	0.2	0.2
Total + Margin	54.1	56.7

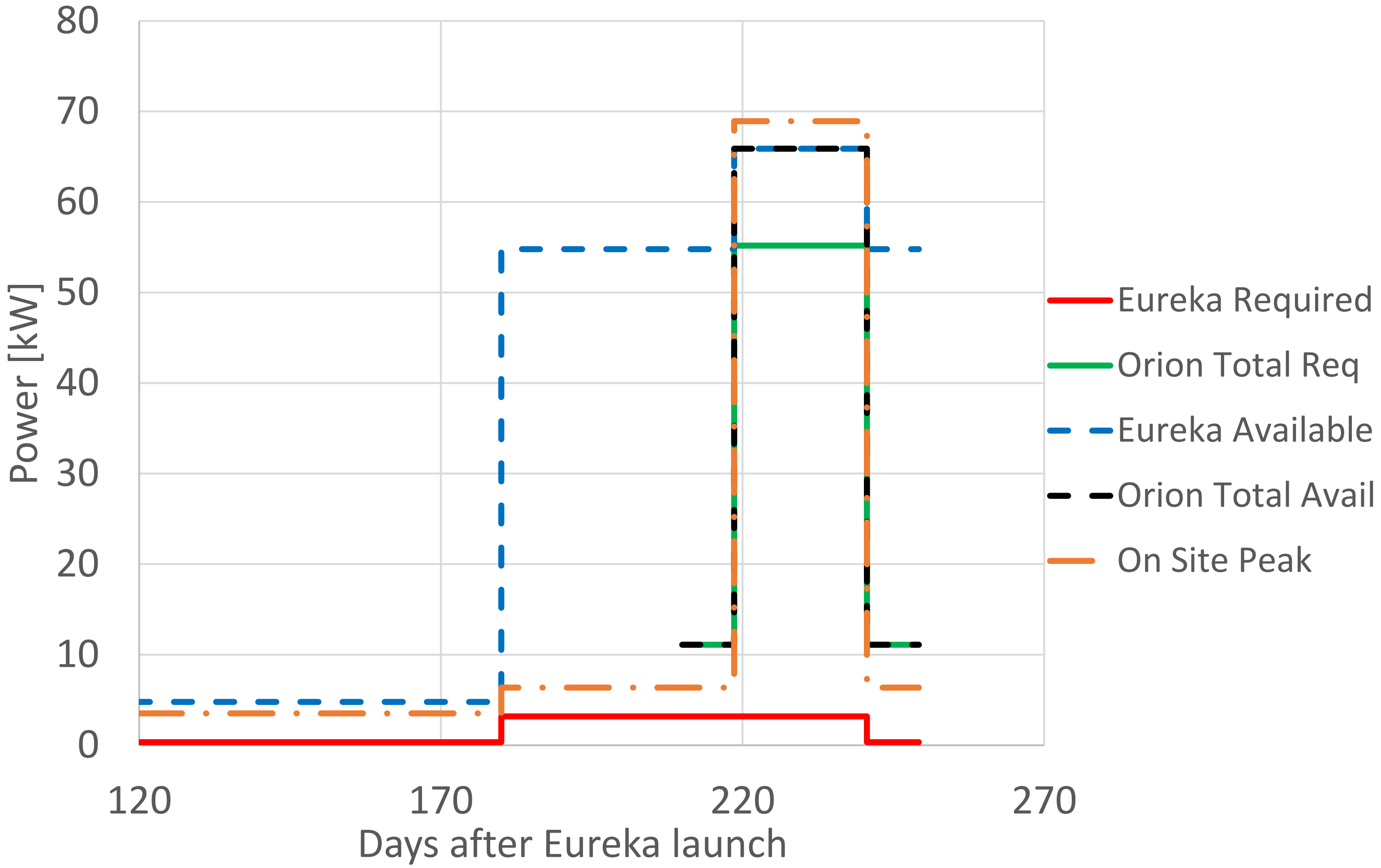
Payload Budget - Eureka

System	Mass [t]	Volume[m³]	Power avg. [kW]
Habitat	3.3		
Science	0.98	13.4	
ECLSS	8.75	3.6	2.3
Workspace		10.8	
EPS	0.23		3.0
TCS	0.04	0.1	1.5
GNC	0.93		257.4
COM	0.08		72.0
OBDH	0.01		20.2
Module Structure	0.5		
Total	14.35	28.0	2.6
Margin	0.2	0.2	0.2
Total + Margin	17.22	33.6	3.2

EPS

Power Budget

- Primary and secondary batteries in Eureka
- Solar array sizing includes required battery charge power
- Peaks covered by batteries



Risk management

- Risks related to all subsystems are rated according to the NASA risk management standard.
- Mitigation strategies are implemented according to the severity
- Almost all critical risks reduced to LOM

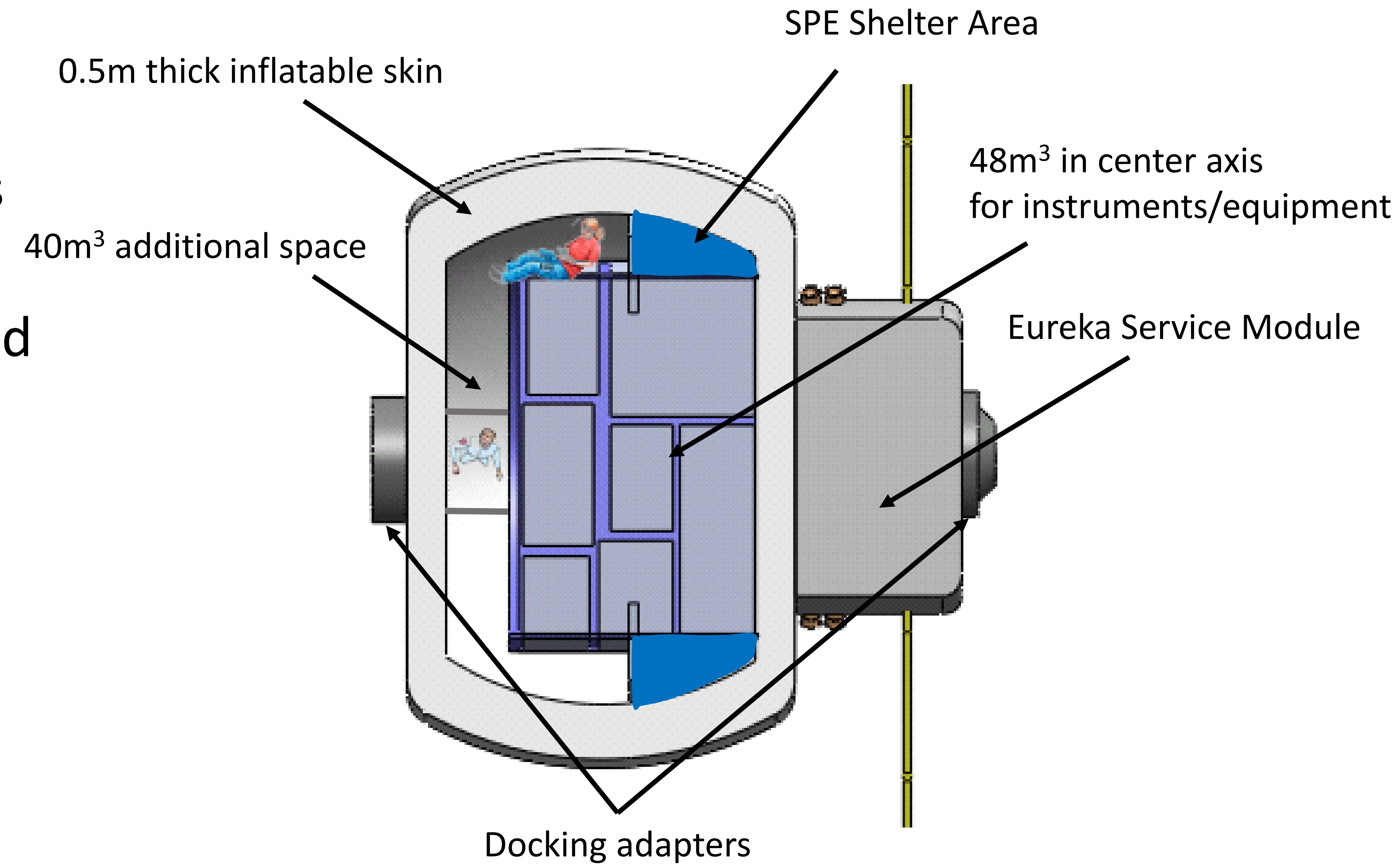
10: Partial failure of critical system shortly after TLI → Trajectories and maneuvers devised to bring crew back to earth

Consequence Index/ Probability Index	1	2	3	4	5
5	23		8		
4			30	21/22	
3	31	12	11/16/17/ 20/24		10
2	3/15	18	2/25/26/2 7	5/6/7/13	14
1	4	1		29	9/19/28

Science Habitat - Eureka

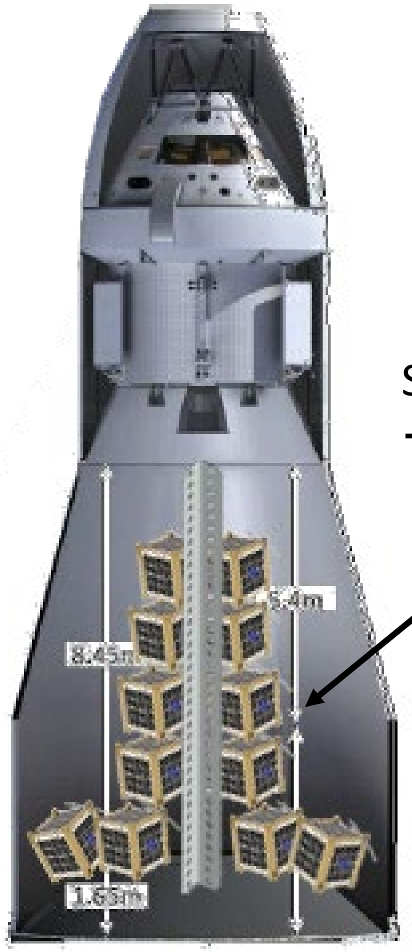
Inflatable

- Based on TransHab studies and Bigelow
- Mass interpolated from available data
- Augments Orion capabilities
- **Length:** 7m
- **Diameter:** 7.5m



Launch configuration

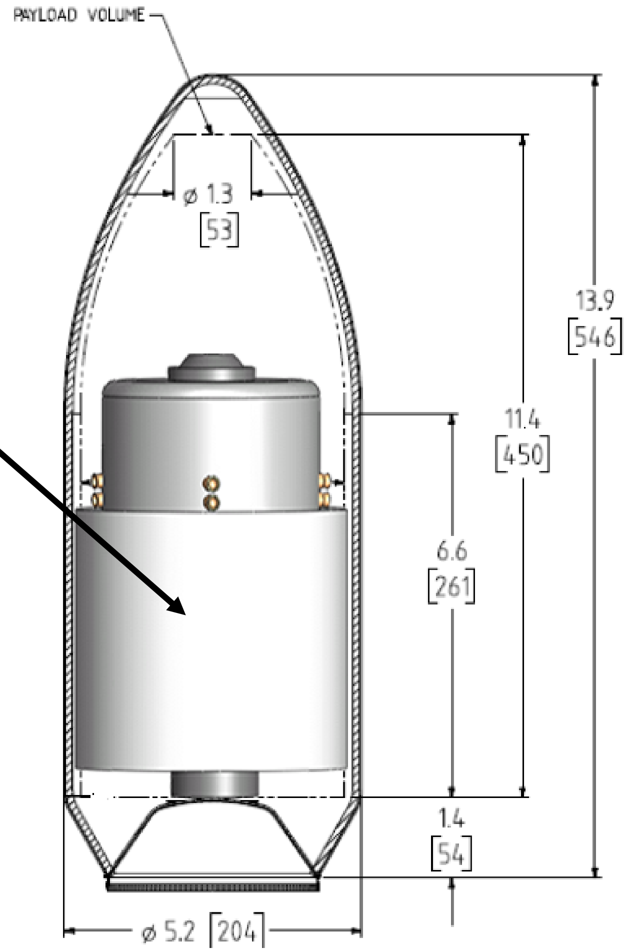
SLS Block 1B



Secondary payload
→ Outreach

Falcon Heavy

Deflated Eureka

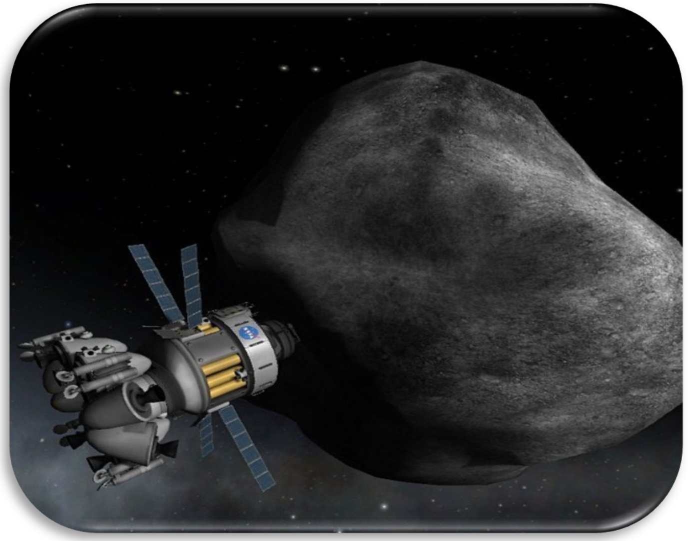


Public Outreach: Tangible Experiences

Space selfies

CubeSats Released at Moon (After Mission)

Arm-Chair Astronauts



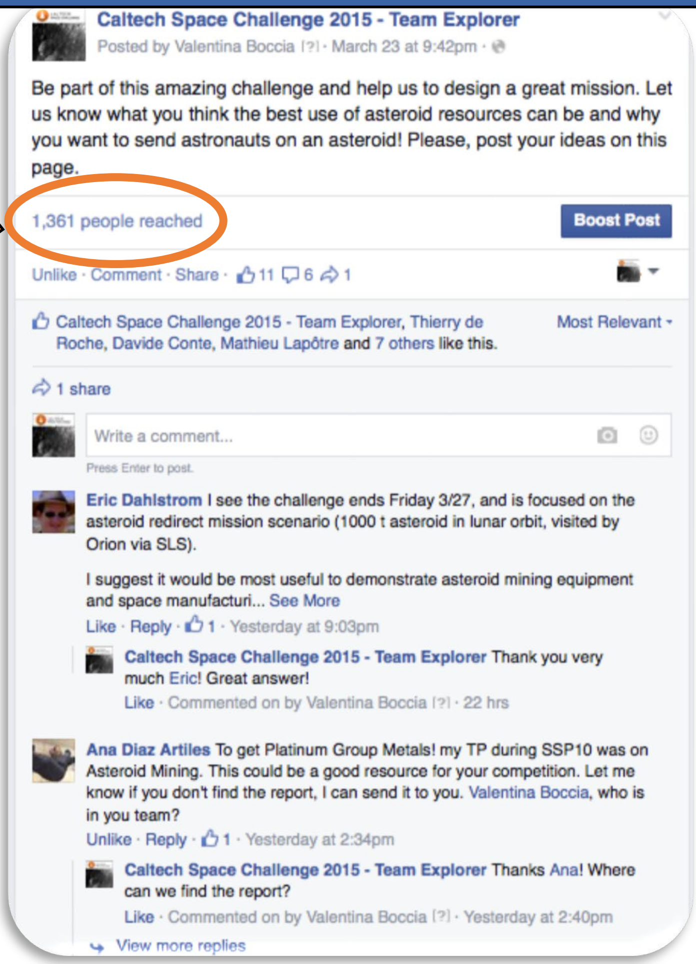
Astronaut Sorbet from Processed Water

Public Outreach: Social Media in Action

Created a Facebook Page

Picked up by the Space Generation Advisory Council

1,500+ People Reached



Discussion on the International Space University Page

Programmatic Considerations: Budget

- Rough estimates of the mission cost are based on the Space Mission Analysis and Design handbook
- Launch costs are best guess and do not include development costs
- Development of common technologies not included: Orion and SLS program, Orion Service Module (MPCV-ESM), Space suit, annual cost of launch and NASA facilities, Bigelow space module

Launch costs

Item	ROM cost (M$)
2.0 Launch Vehicle	
2.1 First launch (Falcon Heavy)	270
2.2 Second launch incl. Orion capsule and service module (SLS block 1B)	2,000
Total	2,270 M$

Programmatic Considerations: Budget

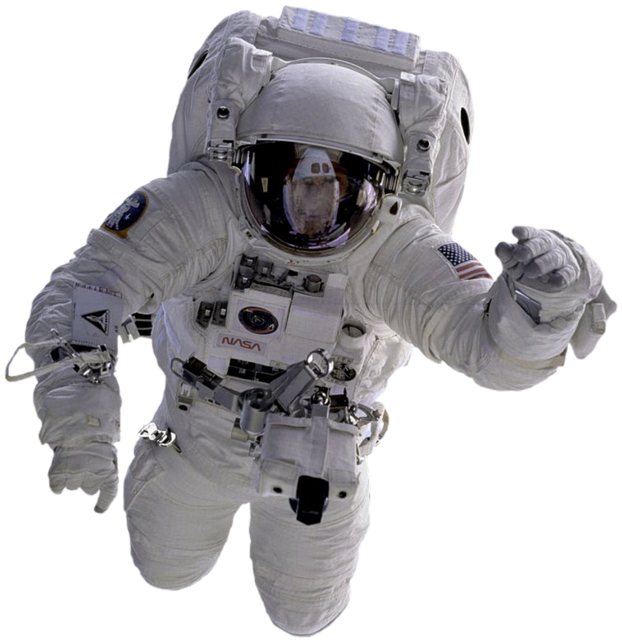
- Rough estimates of the mission cost are based on the Space Mission Analysis and Design handbook
- Launch costs are best guess and do not include development costs
- Development of common technologies not included: Orion and SLS program, Orion Service Module (MPCV-ESM), Space suit, annual cost of launch and NASA facilities, Bigelow Module

Vehicle and operation costs

Item	ROM cost (M$)
1 Science vehicle assembly	
1.1. Inflatable structure	150
1.2. Custom service module	250
1.3. Science and tech demo	700
3.0 Ground Command & Control	50
4.0 Program level	220
7.0. Operations	130
Total (with 20% margin)	1,800 M$

Conclusions: Mission Overview

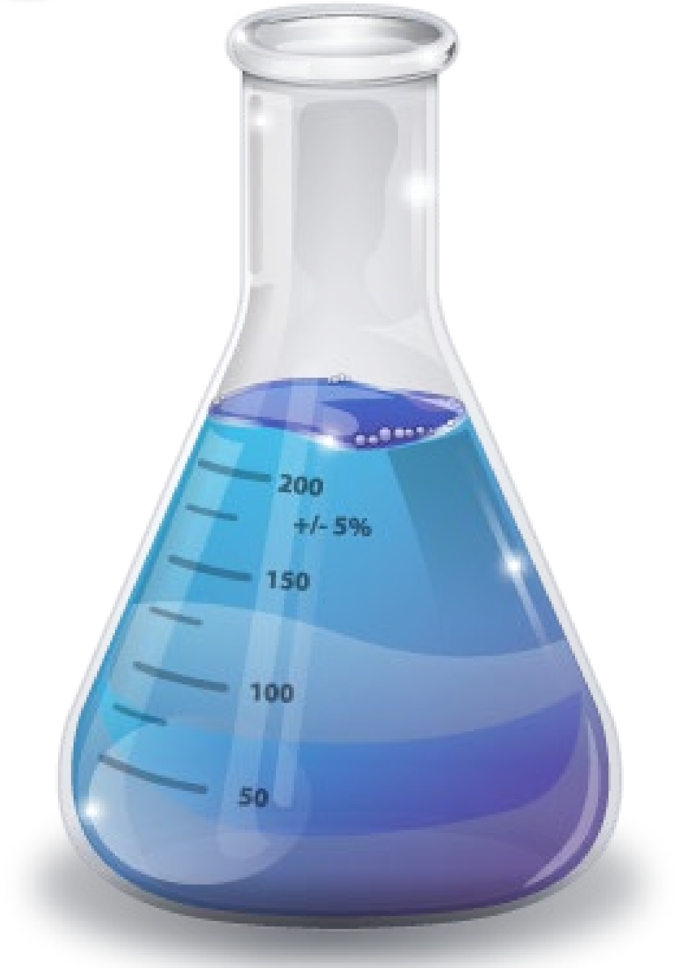
+



x3

39 Days

Conclusions: Measure, Treasure, and Pleasure



Science

Utilization

Outreach

Conclusions: We Should be Having Fun Too!

But Seriously…

Caltech

GALCIT

Keck Institute for Space Studies

Moore-Hufstedler Fund
mhf.Caltech.edu

SPACEX

agi

NORTHROP GRUMMAN

LOCKHEED MARTIN

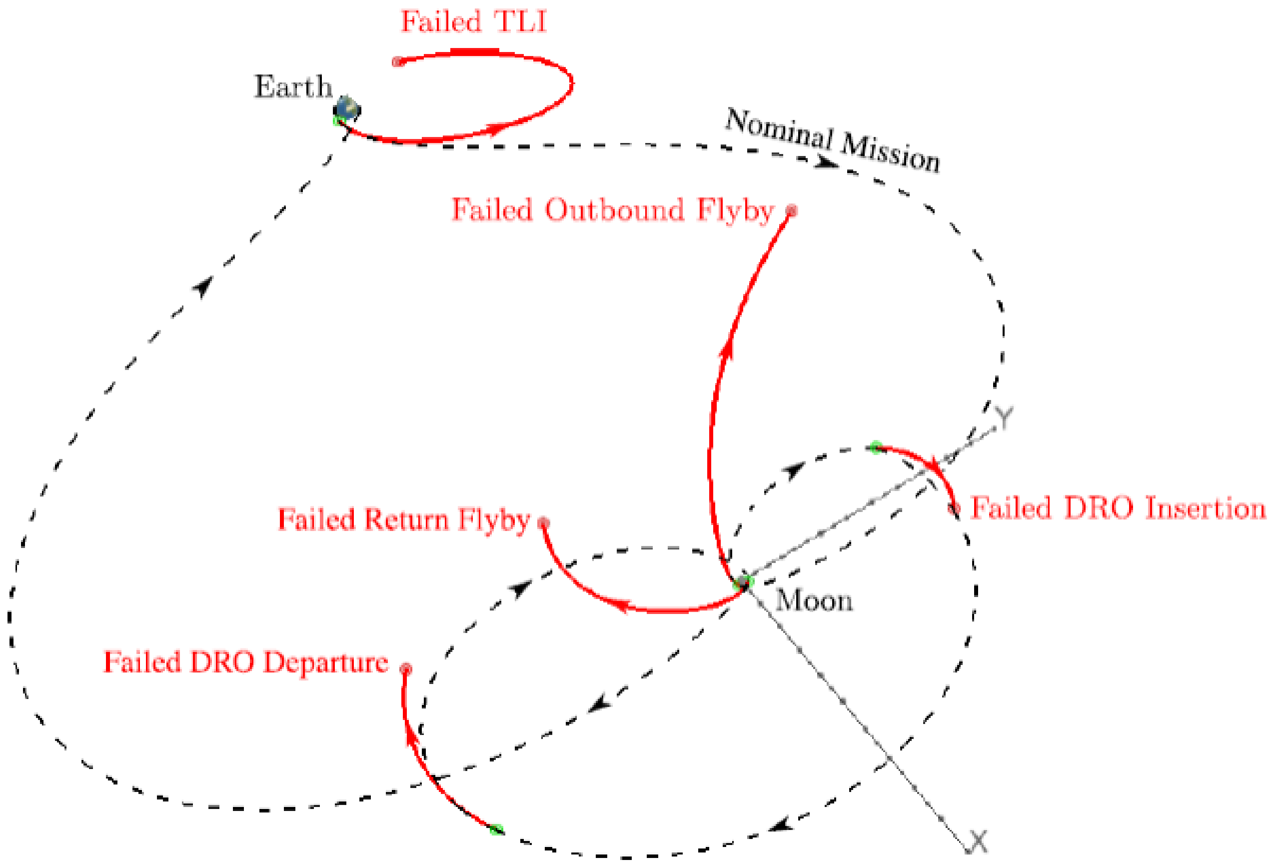
JPL

MILLENNIUM SPACE SYSTEMS

And to the Caltech Space Challenge mentors, speakers, and organizers!

L-DORADO

Trajectory Planning: Direct Transfer Abort Option



Williams & Condon, “Contingency Trajectory Planning for the Asteroid Redirect Crewed Mission,” Paper AIAA 2014-1697

Communications, Command and Data Handling

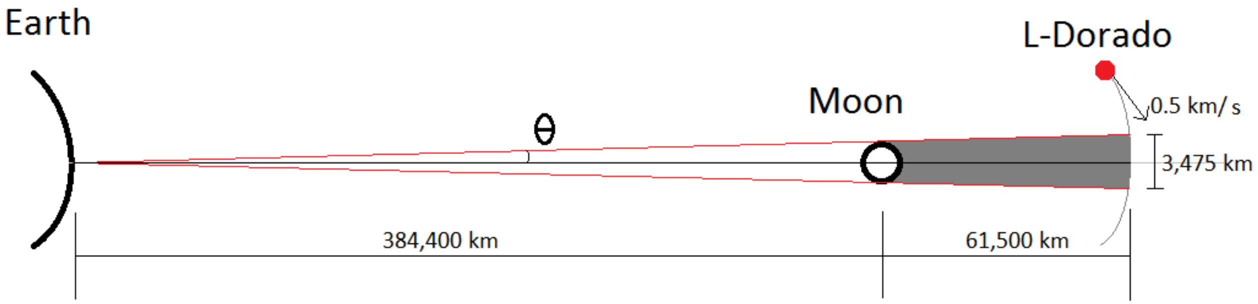
Two links :

1) Telemetry link
2) Crew voice communiction link

High system complexity : Science Data, HD cameras, housekeeping data

C&DH system : 10 kg, 15 dm^3 and consume 25 W (*'SMAD', Wertz*)

Time of lunar blackout time ~ 2 h (no operations that require communications fidelity.



ARCHITECTURE

Link budget assumptions:

- Data rate: 12 Mbps
- **X-band frequencies** : ~8 GHz
  Total losses : 12 dB
  Thermal noise : neglected
  Ground station : 15 m dish, 200 W
- Various losses outside line losses: 12 dB
- S/C dish of 10 cm diameter and a power of 20 W
- Link closes with margins of 20 dB on the up- and 11 dB downlink.

We Had Fun (Ridiculous) Ideas Too

Break up the asteroid and send it to earth to create a spectacular meteor shower. Expect a huge spike in weddings and wedding proposals on the day of the event.

Back-up Slides

“Hot” Issues

- Working hard across disciplines to get everything in one launch. Going to be close.
- Difficult to find mass, power, volume, cost, etc… information on existing science instruments.
- In situ resource processing doesn’t have much real-world experiments to study.
- Looking to push the envelope on creativity. Would like to get your feedback on some concepts. (See back up slides)

Science Missions
Use the resources for future moon and mars missions.
Use a mirror to focus the sun to sinter material.
Build a symbiotic greenhouse where microbes create the resources needed to fuel the plants.
Leave an autonomous station that continues to research and process the asteroid
Use the asteroid as a platform for deep space communications. It could feature both laser powered as well as traditional EM technology. It may be even more valuable as a telecommunications platform if it's in a polar orbit around the moon.
Install telescopes that will benefit from using the asteroid as an effective sun and earth shield.
Use it as an emergency station for moon travelers.
Use the gases and water collected from the asteroid to power a small rocket that navigates around, or possibly to, the moon. It would be more of a steam rocket then a high Isp rocket.
The asteroid's relatively wide orbit around the moon may make it a good platform for radio wavelength observations. The asteroid would also help block polluting signals from the earth.
Use the asteroid to demonstrate micro-gravity refueling.
Use the asteroid for radiation protection, either by boring into it or breaking it into smaller pieces that are installed around a vehicle.

Science Missions
Use bacteria or microbes to digest the asteroid over time. A bag or balloon around the asteroid collects the gases for analysis and use later.
Use the mass of the asteroid to help demonstrate artificial gravity methods.
Use the asteroid as a platform for the Mars Cycler concept.
Beam the 50 kWatts from the ARM to earth to study space-based energy sources. Alternatively, beam the power to a relatively nearby test unit.
Cut the asteroid in half with a laser. Science!
Lunar science base. Green house on moon. Futuristic approach. Telerobot control
Crash the asteroid on the moon, Mars, Venus, etc... to create a plume that can be studied.
Use the minerals from the asteroid to create a solar panel.
Use the moon's tidal forces to break apart the asteroid.
Break the asteroid into pieces, then embed life in the asteroid and send them outside the solar system.
Demonstrate the ability to precisely target and collide with another asteroid.
Use a laser to shape the asteroid, get it to start spinning, and become a reaction wheel.
Testing asteroid deflection technologies for earth protection.
Break up the asteroid and send it to earth to create a spectacular meteor shower. Expect a big spike in wedding proposals.

Launch 1: Falcon Heavy Launch

Launch Date:
January 4th, 2024
Payload: Science Module

Rocket	Mass to TLI (kg)
Delta IV Heavy	11,350
Falcon Heavy	16,280
SLS Block 1	21,660

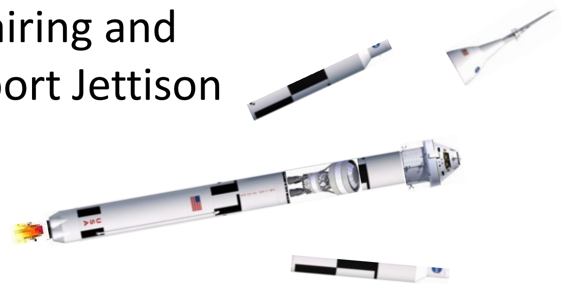
Must deliver science module mass of 12,000 kg to Trans-Lunar Injection (TLI)

- Only Falcon Heavy and Space Launch System (SLS) are sufficient
- SLS may only be able to launch once per year; need SLS for Orion launch
- Thus, Falcon Heavy will be used to launch science module

Launch 2: Space Launch System 1B Launch

Launch Date:
January 4th, 2025
Payload: Orion

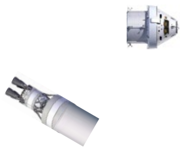
Payload Fairing and Launch Abort Jettison
T + 472 s



Core & Upper Stage Separation
T + 476s

Upper Stage Ignition
T + 486s

Upper Stage Separation
T + 1,821 s



SRB Jettison
T + 128 s

SLS Variant	Total Delivered Mass to TLI (kg)	Supplementary Mass (kg)
Block 1	28,990	not available
Block 1B	46,960	11,580
Block 2	52,410	17,030

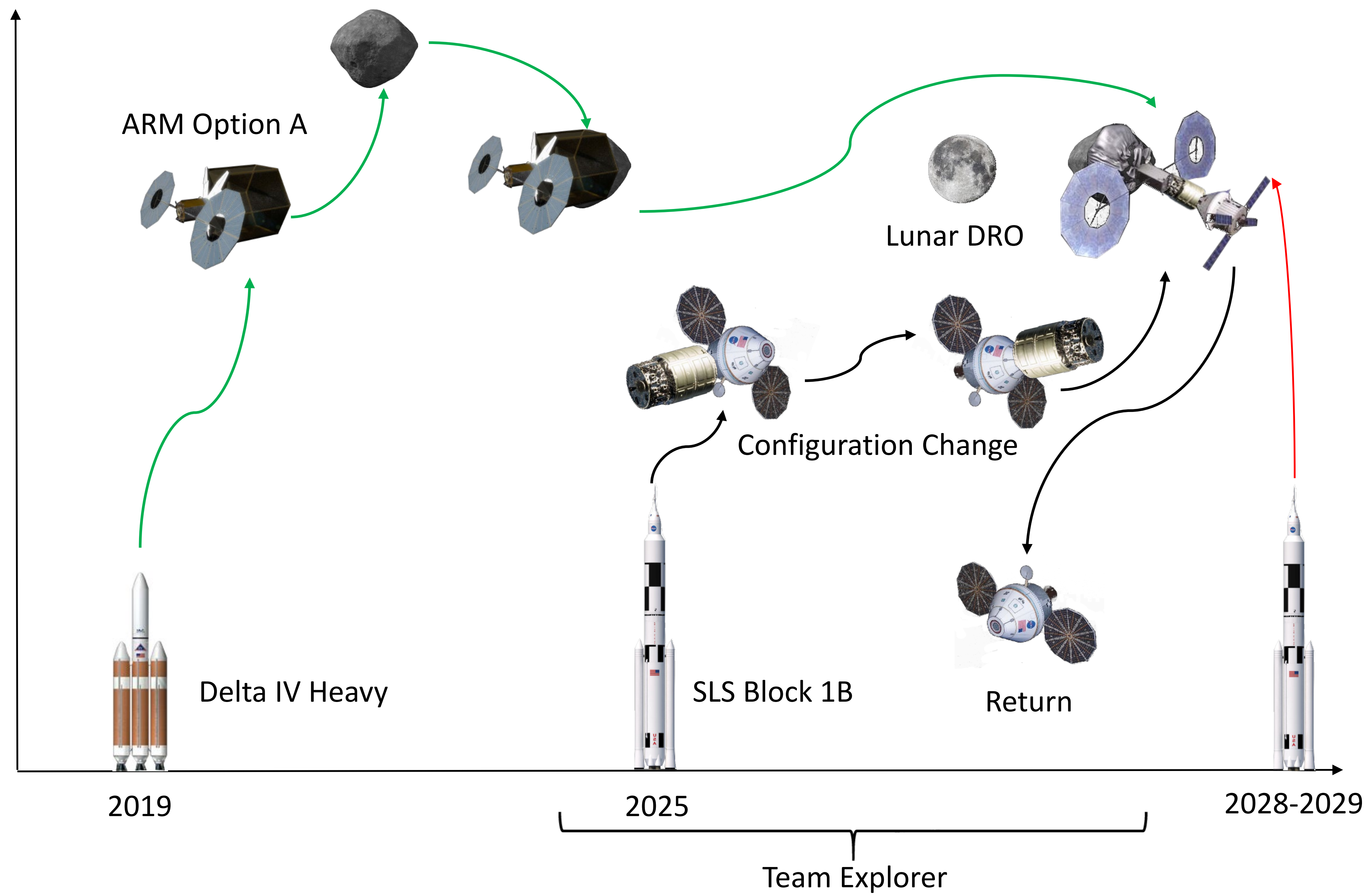
Supplementary mass is total mass subtracted by Orion launch mass of 35,385 kg

Liftoff
T = 0 s

- Space Launch System Block 1B (available 2021) and Block 2 (available 2024?) are sufficient
- SLS Block 1B will be used; SLS Block 2 can be used if available -> Only one launch needed
- Stage breakdown by thrust, specific impulse, and mass available in backup slides

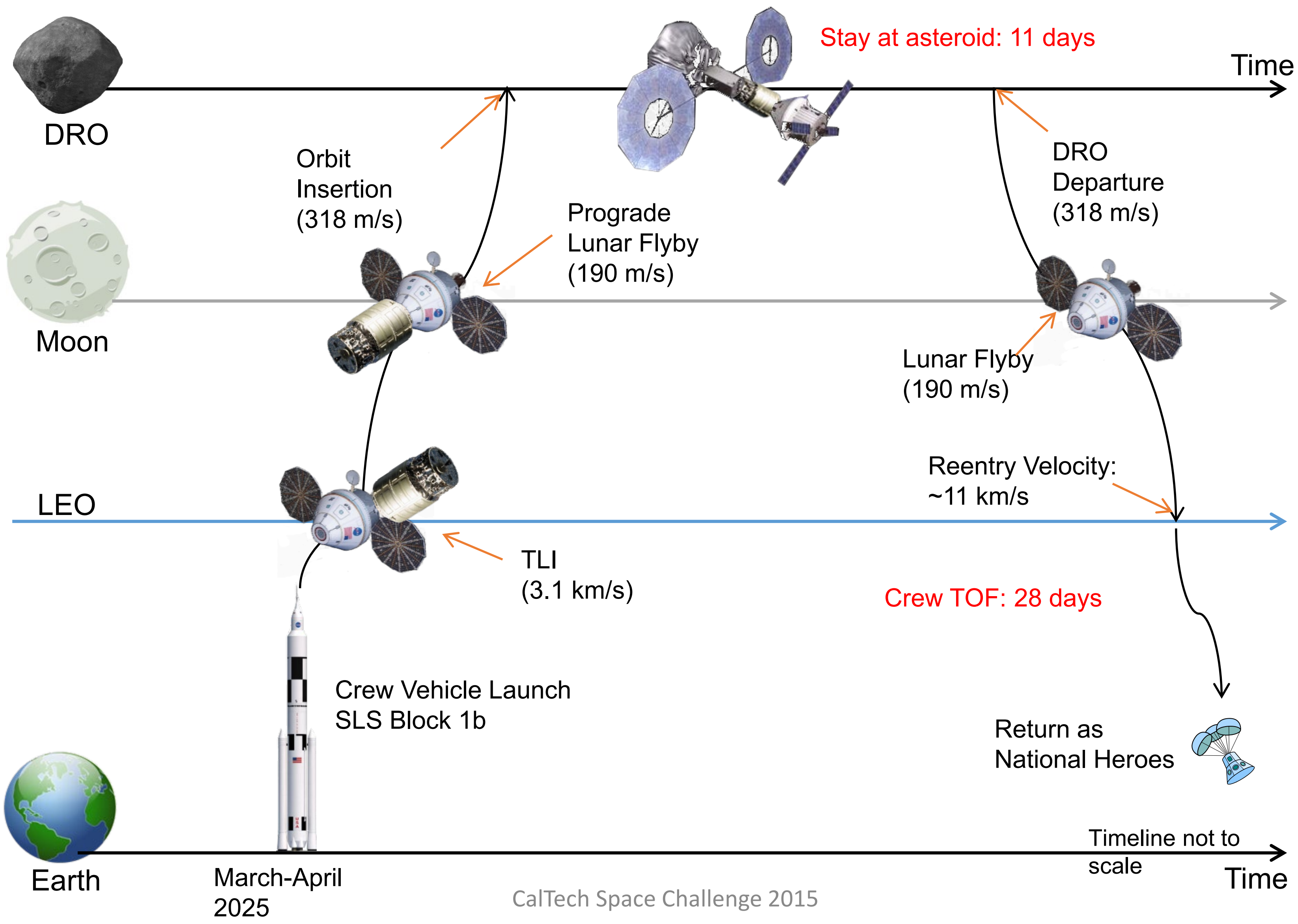
Launch Backup

Stage	Variant	Rocket Engine	Thrust (kN)*	Isp (s)^	Burn Time (s)	Dry Mass (t)*	Propellant Mass (t)*
0	1/1B	2x Modified SS SRBs	28024	252.2	128.4	104 0.	631.5
	2	2x New Composite ATK Boosters	40031	272.5	110	84	790
1	1/1B/2	4x RS-25D/E	8277	409.1	476	102	979.5
2	1	1x RL-10-B2	110	461.5	1118	3.8	26.9
	1B/2	4x RL-10-C1	425	448.5	1335	15	129

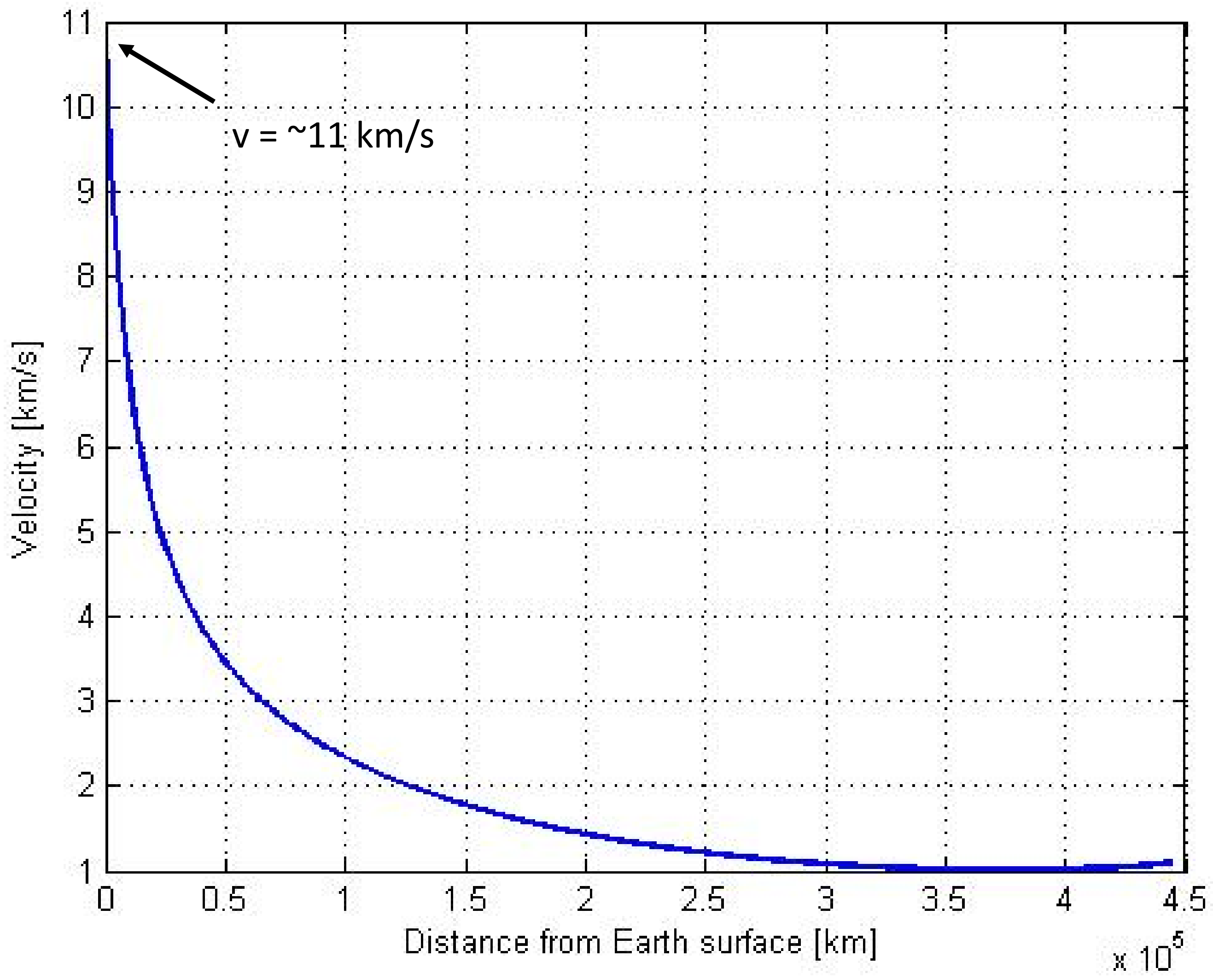


ARM Option A
Lunar DRO
Configuration Change
Delta IV Heavy
SLS Block 1B
Return
2019
2025
2028-2029
Team Explorer

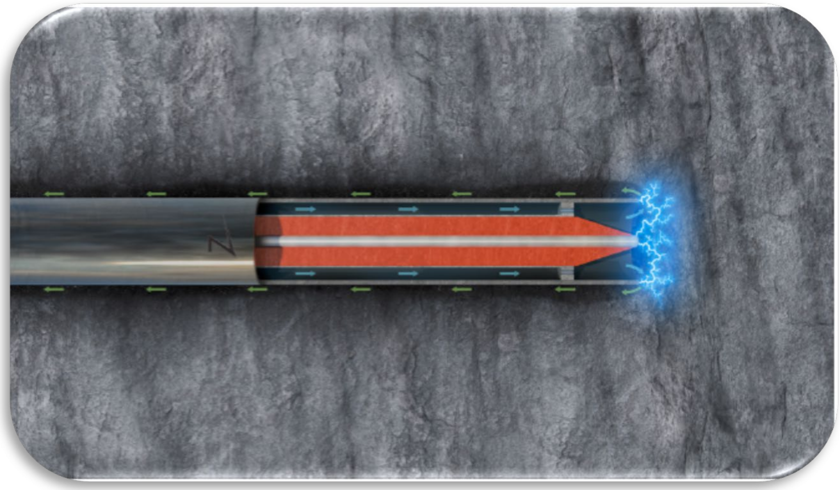
Mission Overview



Trajectory Planning: Reentry Velocity

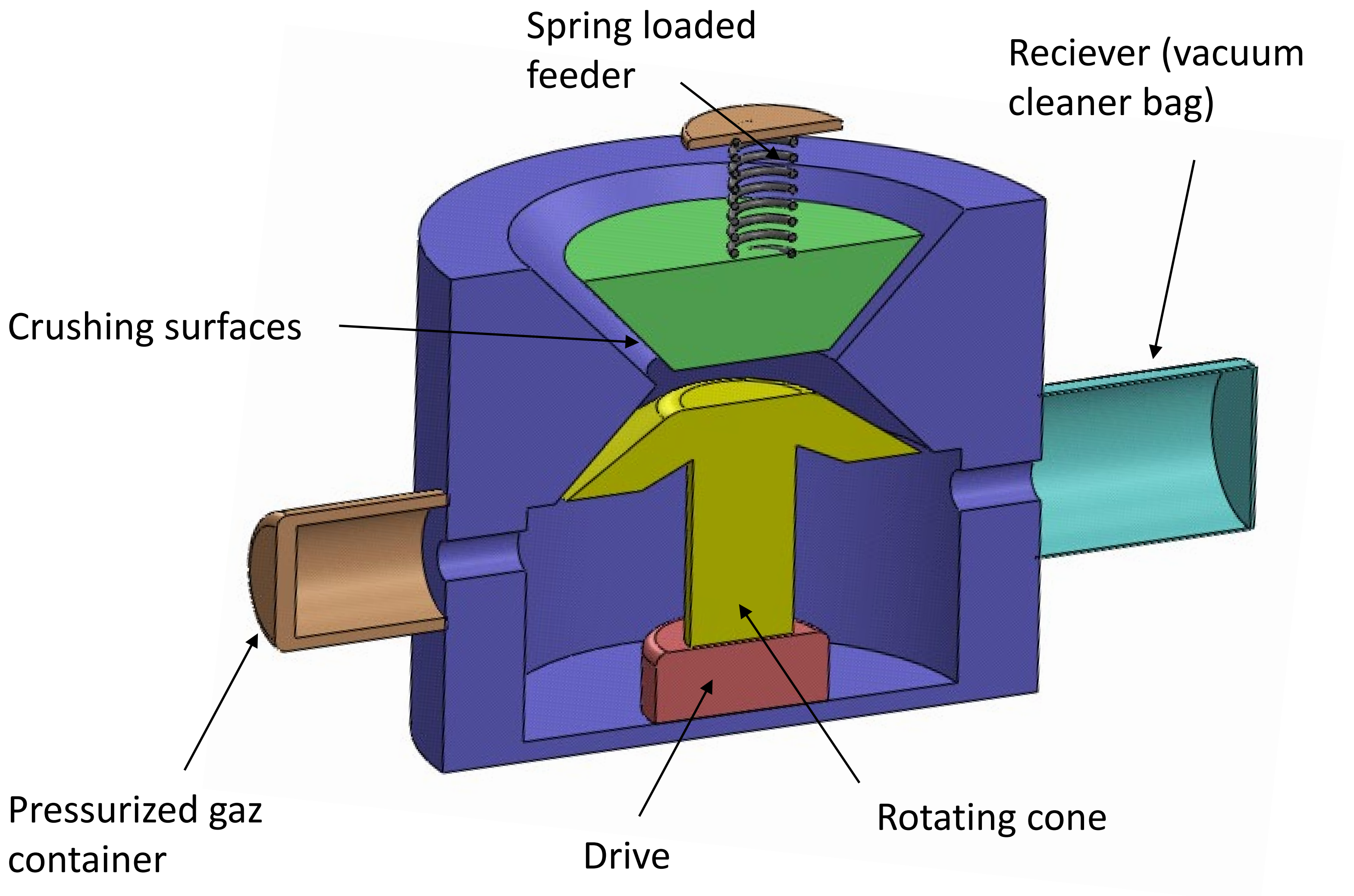


Tech Demo: Plasma Drill and Radiation Protection

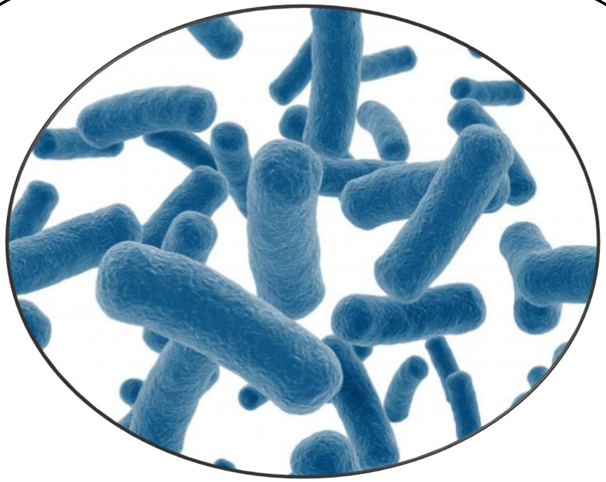


ARC (Asteroid Regolith Crusher)

- Cone crusher
- Used on earth
- Development needed for deep space implementation
- Needs self cleaning environment



ISRU: Microbe Powered Greenhouse



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Alternative Pyrolysis Heating Methods (Backup)

- 30 kW microwave emitter
  - ~65-78 % efficiency – difficult to remove waste heat
  - Safety concerns with crew nearby

- Solar thermal – parabolic mirrors
  - Long set up time, limited EVAs
  - Area >20m2
  - Pyrolysis chamber must be uninsulated
  - Astronauts could pass in front of beam

		1	**2**	**3**
Heating method **Criteria**	Weight (1 -> 5)	**Solar parabolic mirror**	**Micro-waves**	**Resistive heating**
Weight	5	3	3	5
Crew safety	5	2	3	5
Power	4	5	2	3
Operation simplicity	4	3	4	4
Scalability	4	4	3	5
Processing time	3	3	5	4
Volume	3	3	4	5
Cost	2	3	3	4
Energy efficiency	2	5	2	3
Waste heat	2	5	3	4
Total	34	**97**	**99**	**133**

Engineering

- Engineering of the vehicles, tools, and instruments primarily relies on the subcontractors.
- The program levies requirements based on mission level analysis and assigns factors of safety they must work to.
- The general concept is to define what they must not do and not how they must do it.

Programmatic Considerations (Backup)

- Cost

Item	ROM cost (M$)	Comment	Num FTE over 10 years
1.0 Space Vehicle			
1.1. Orion capsule with service module	1000	From web	
1.2. Service transfer vehicle	0	Assumes European contribution	
1.3. Science payload			
1.3.1. Laboratory structure	148	USCM8: ~(23 k$/kg * 4000kg * 150%)	
1.3.2. Laboratory thermal control	6	USCM8: ~(23 k$/kg * 136kg * 150%)	
1.3.3. Science instruments	500	20 instruments @ 20 M$ + 25%	
2.0 Launch Vehicle (launch cost)	1000	From web	
3.0 Ground Command & Control	5	3% of laboratory cost	
4.0 Program level			
4.1. System engineering	31	20% of laboratory cost (not instruments)	16
4.2. Program management	24	15% of laboratory cost	12
4.3. System integration and test	24	15% of laboratory cost	12
4.3. Product assurance	5	3% of laboratory cost	3
4.5. Other	0		
5.0 Flight Support Operations	0		
6.0 Aerospace Ground equipment	0		
7.0. Operations			
7.1. PMSE	24	15% of laboratory cost	
7.2. Space segment maintenance	0		
7.3. Ground segment	9	30 engineers + 10 tech, for 2 months	

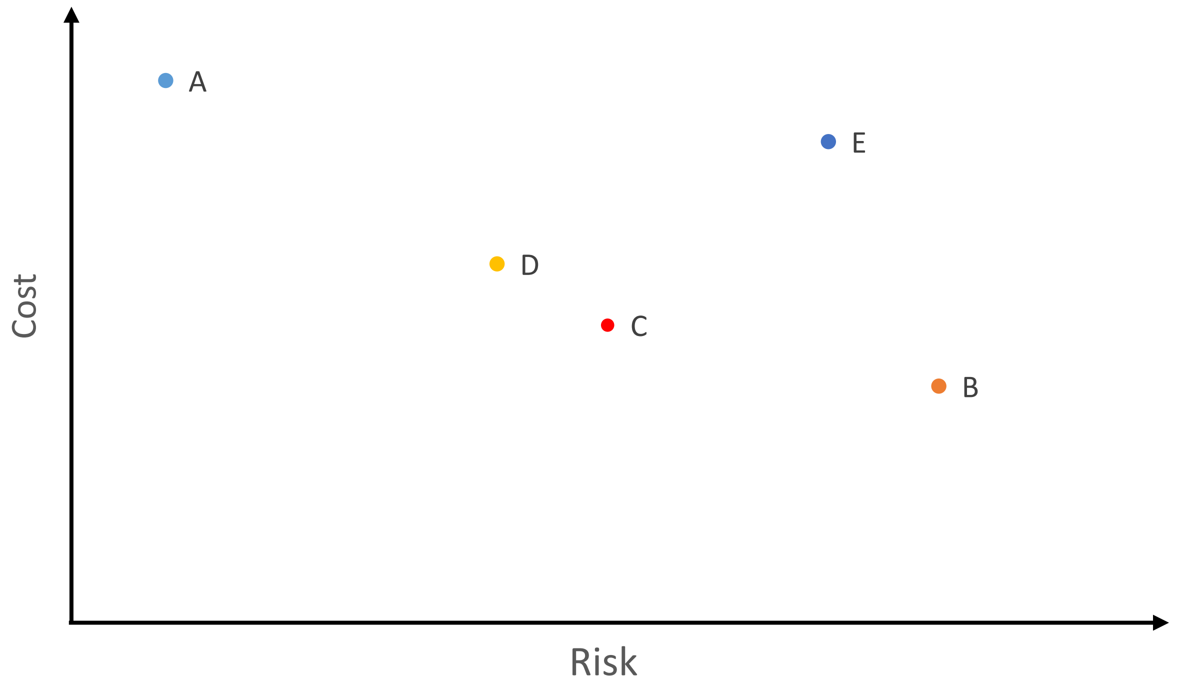
Team Members

First Name	Last Name	Focus Areas
Bill	Tandy	Proposal Manager
Chris	Wynard	
Dan	Fries	Systems Engineering
Davide	Conte	
Henna		
Koki	Ho	
Lee		
Max		
Marilena		
Mat		
Max		
Priyanka		
Rahul		
Simon	Dandavino	
Takeshi	Gagliardi	
Thierry	de Roche	Extraction
Valentina	Boccia	Science

Launch

Launch concept trade-off

A	Orion + Service Module in SLS Block 1B and Habitat in Block 1B
B	Orion + Service Module in Block 1B and Habitat + Heavy Lift + Upper Stage in Payload for ballistic TLI
C	Orion + Service Module in Block 1B and Inflatable Habitat + Heavy Lift for ballistic TLI
D	Orion + Service Module in Block 1B and Habitat + Heavy Lift + SEP to lunar DRO
E	Orion + Service Module in Block 1B and inflatable Habitat + Heavy Lift + SEP to lunar DRO



Option B - large, cryogenic upper stage, modified payload fairing

Option D - more costly due to customized habitat, additional ARM derived SEP module. Can-designs have large heritage, ARM is intentionally developed modularly to reuse

Option C - good compromise between risk and cost, chance to develop inflatables further, key technology for future missions. Enough payload volume and mass, including sufficient margins.

Risk Management

Critical Risks

8: Translunar injection maneuver is not successful
→ If the upper stage delivers only a delta-v of 2.92 km/s or lower, the mission cannot be completed (still working on mitigation!)

21: Eclipse by moon/earth

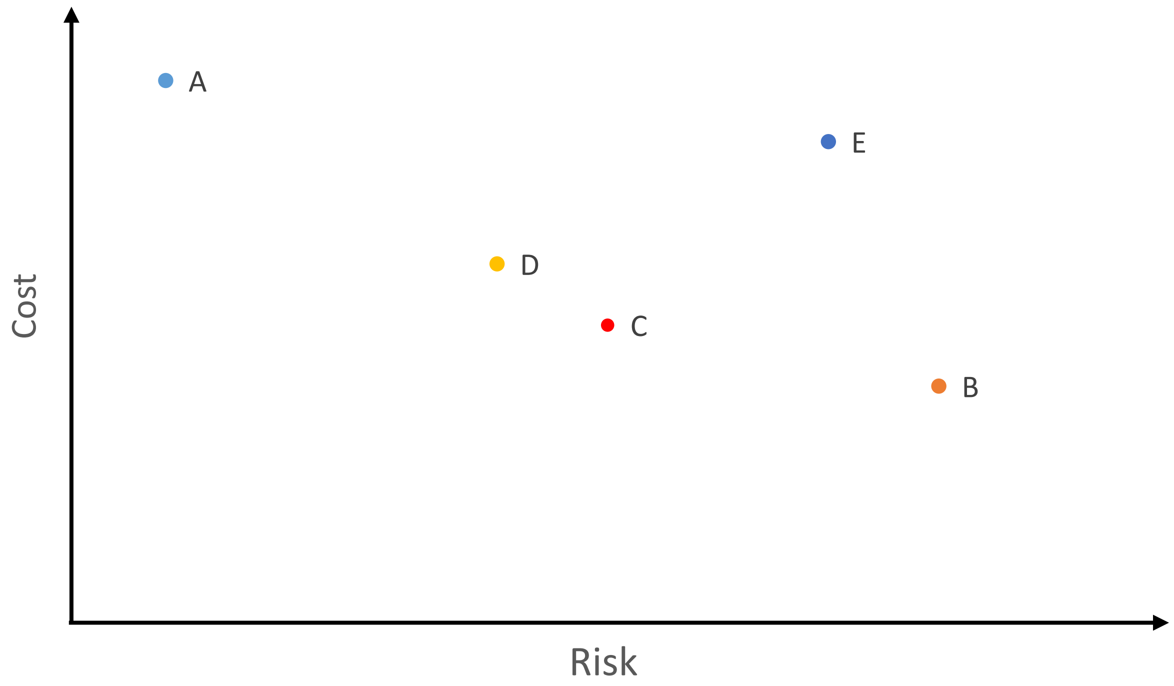
→MLI in skin of Eureka to ensure thermal inertia. Include heating device.

22: Eclipse by asteroid

→Dock in such a way that spacecraft is not eclipsed. Include heating device.

Launch Trade Example

A	Orion + Service Module in SLS Block 1B and Habitat in Block 1B
B	Orion + Service Module in Block 1B and Habitat + Heavy Lift + Upper Stage in Payload for ballistic TLI
C	Orion + Service Module in Block 1B and Inflatable Habitat + Heavy Lift for ballistic TLI
D	Orion + Service Module in Block 1B and Habitat + Heavy Lift + SEP to lunar DRO
E	Orion + Service Module in Block 1B and inflatable Habitat + Heavy Lift + SEP to lunar DRO



Option B - large, cryogenic upper stage, modified payload fairing

Option D - more costly due to customized habitat, additional ARM derived SEP module.
Can-designs have large heritage, ARM is intentionally developed modularly to reuse

Option C - good compromise between risk and cost, chance to develop inflatables further, as a key technology for future missions. Enough payload volume and mass, including sufficient margins.

Eureka

Habitat trade-off

- Science equipment and experiments require considerable amount of space
- Improved radiation shielding allows for extended stay
- Inflatables as key technology for future manned exploration and utilization missions
- More usable payload per launch
- Inflatable heritage does exist

	"Can" design	Inflatable
Living/Working Space	+	+++
Heritage	+++	+
Radiation Shielding	++	+++
Mission Duration	+	++
Tech. advancement	+	++
Mass	+	++
Cost	++	+
Total	11	14

Programmatic Considerations (Backup)

- Cost

Item	ROM cost (M$)	Comment	Num FTE over 10 years
1.0 Space Vehicle			
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7.0. Operations			
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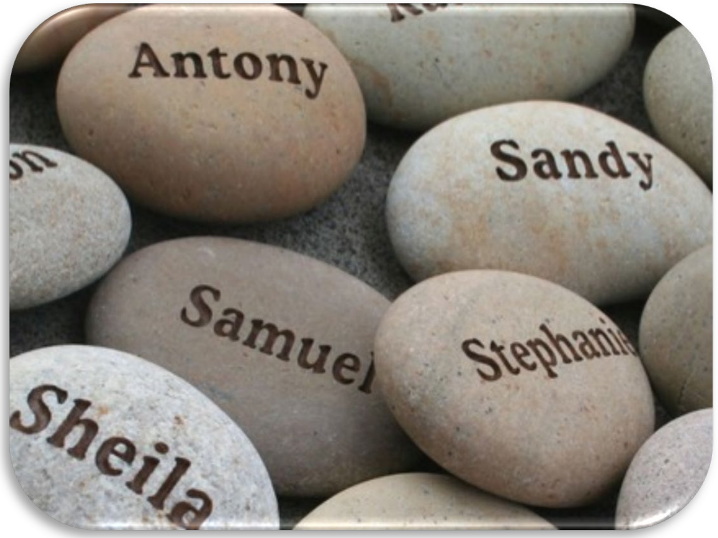
Public Outreach: Tangible Experiences

Art Using Returned Asteroid Material

CubeSats Released at Moon (After Mission)



Name the Asteroid
Leave Disc of Names

Astronaut Sorbet from Processed Water

References

- TBD

Programmatic Considerations