National Aeronautics and
Space Administration

Mars Sample Return Capability Development: Mars Ascent Vehicle and Mars On-Orbit Rendezvous

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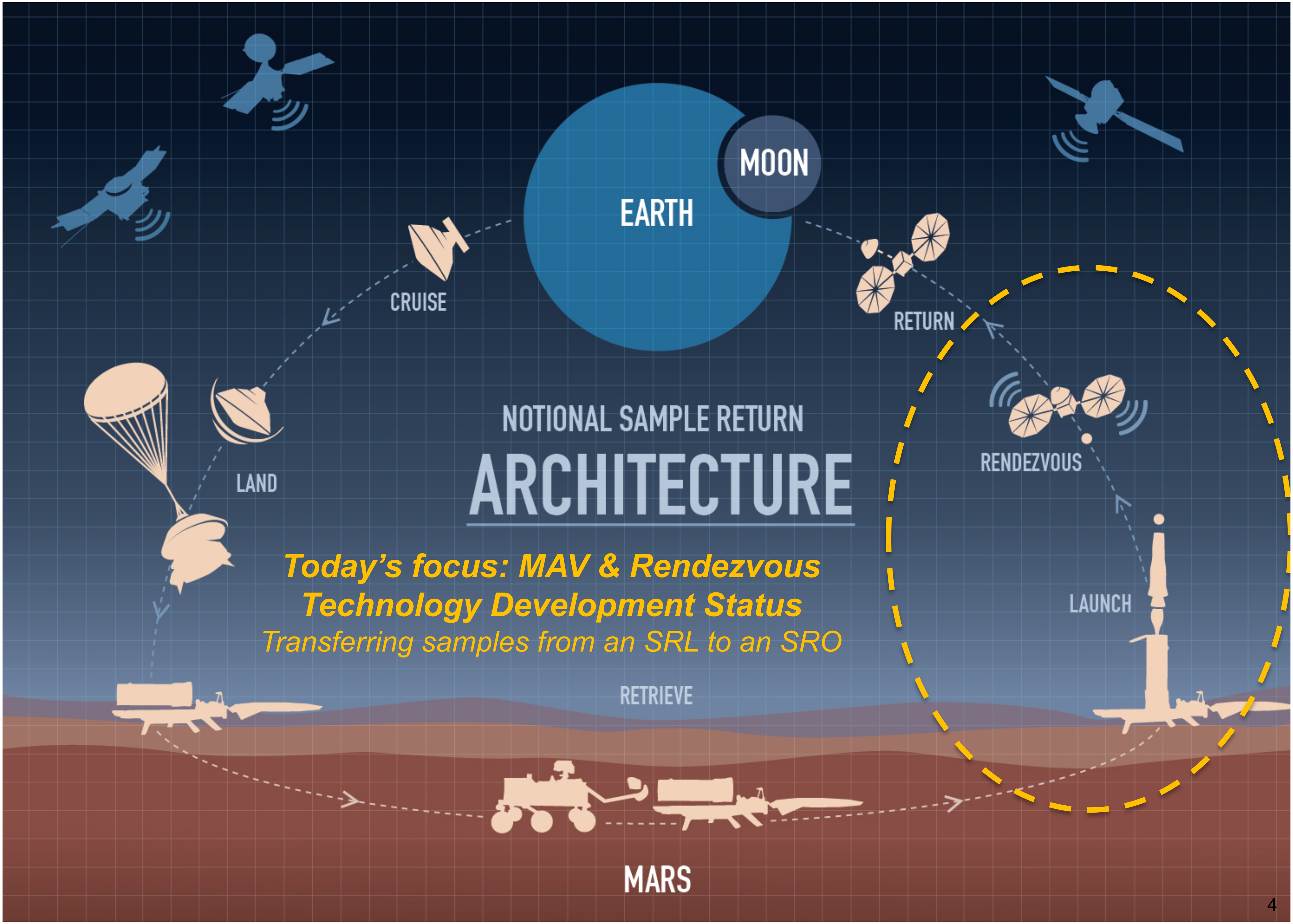
Executive Summary

- Mars Ascent Vehicle and Rendezvous are key capabilities that would be needed for Mars Sample Return
  - A Sample Retrieval Lander's MAV would launch an Orbiting Sample (containing collected samples) into stable Mars orbit
  - A Sample Return Orbiter would perform on-orbit Rendezvous w/ OS for Earth return
- Focused technology developments have advanced the maturity of the MAV and Rendezvous capabilities
- Future developments would establish readiness for SRL/SRO launch as early as 2026

Outline

- Notional MSR Campaign Overview
- Capability Development Status
  - Mars Ascent Vehicle
  - Orbiting Sample
    - Fundamental interface between an SRL and an SRO
  - Mars On-orbit Rendezvous concept
- Summary

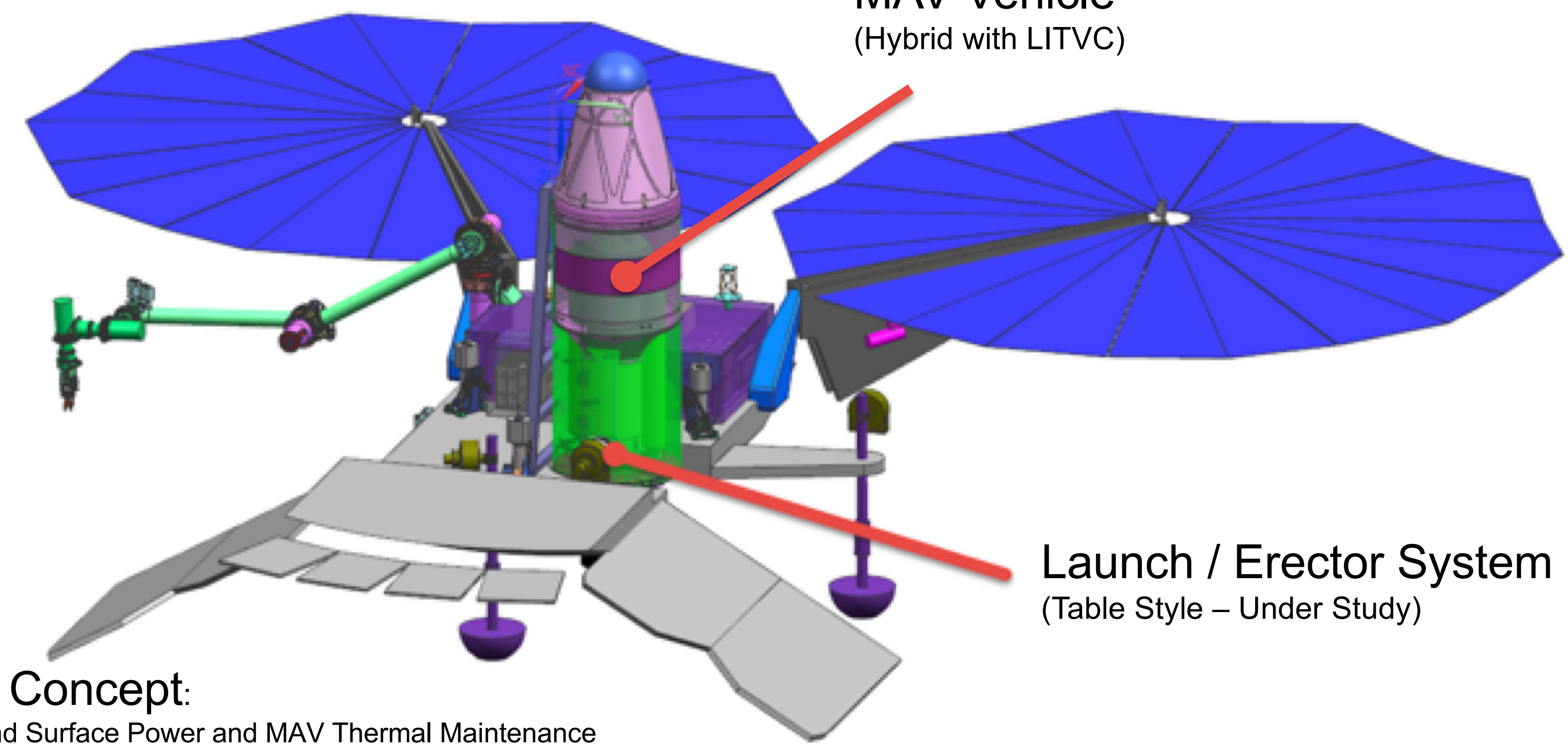

MOON
EARTH
CRUISE
RETURN
LAND
NOTIONAL SAMPLE RETURN
ARCHITECTURE
RENDEZVOUS
Today's focus: MAV & Rendezvous
Technology Development Status
Transferring samples from an SRL to an SRO
LAUNCH
RETRIEVE
MARS

MAV Technology Development

MAV Concept Overview

Driving MAV Requirements:

- ~300-400 km, “due east” circular orbit
- 12 kg Orbital Sample Canister Payload
- Launch from potential M2020 Landing Sites
- 9 months surface survivability with SRL support
- Cold (-20ºC) Operational temperature



Lander Concept:

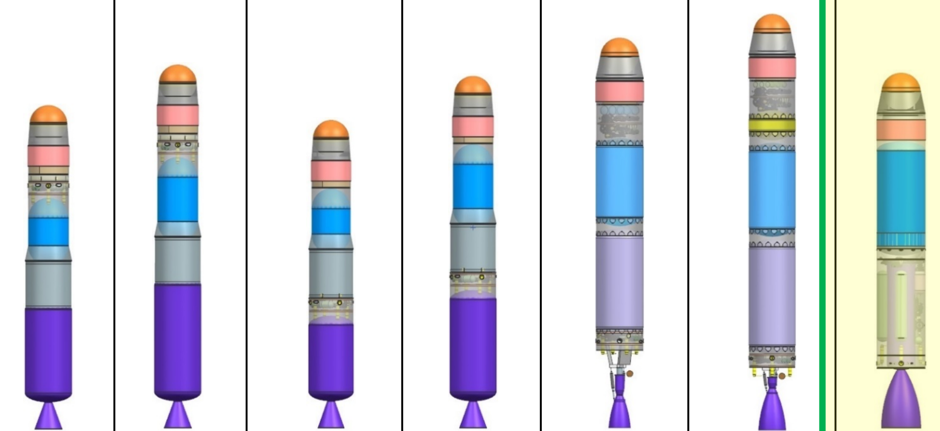
- Cruise and Surface Power and MAV Thermal Maintenance
- Launch Tube with Thermal Insulation to Minimize Energy Costs
- MAV Navigation Initialization
- Erector and Initial Launch Stability

Mars Ascent Vehicle 2015 Case Studies

- JPL/MSFC/LaRC carried out trade study in FY15 of MAV implementation options
  - Solid-Solid two-stage
  - Liquid bi-prop SSTO
  - Hybrid SSTO
- Based on propulsion performance and thermal accommodation, Hybrid SSTO option selected as current focus

2015 MAV Architecture Study

	Case 1a	Case 1b	Case 2a	Case 2b	Case 5	Case 6	Case 7
	Solid-Solid G-G	Fixed Solid-Solid G-G	Solid-Solid G-U	Fixed Solid-Solid G-U	SSTO Pump BiProp	SSTO Reg. BiProp	SSTO Hybrid
GLOM:	319 kg	342 kg	274 kg	297 kg	255 kg	270 kg	219 kg
Length:	2.64 m	2.96 m	2.51 m	2.87 m	3.21 m	3.39 m	2.89 m
AFT:	-58 C	-58 C	-58 C	-58 C	-90/-44 C	-90/-44 C	-90/-66 C

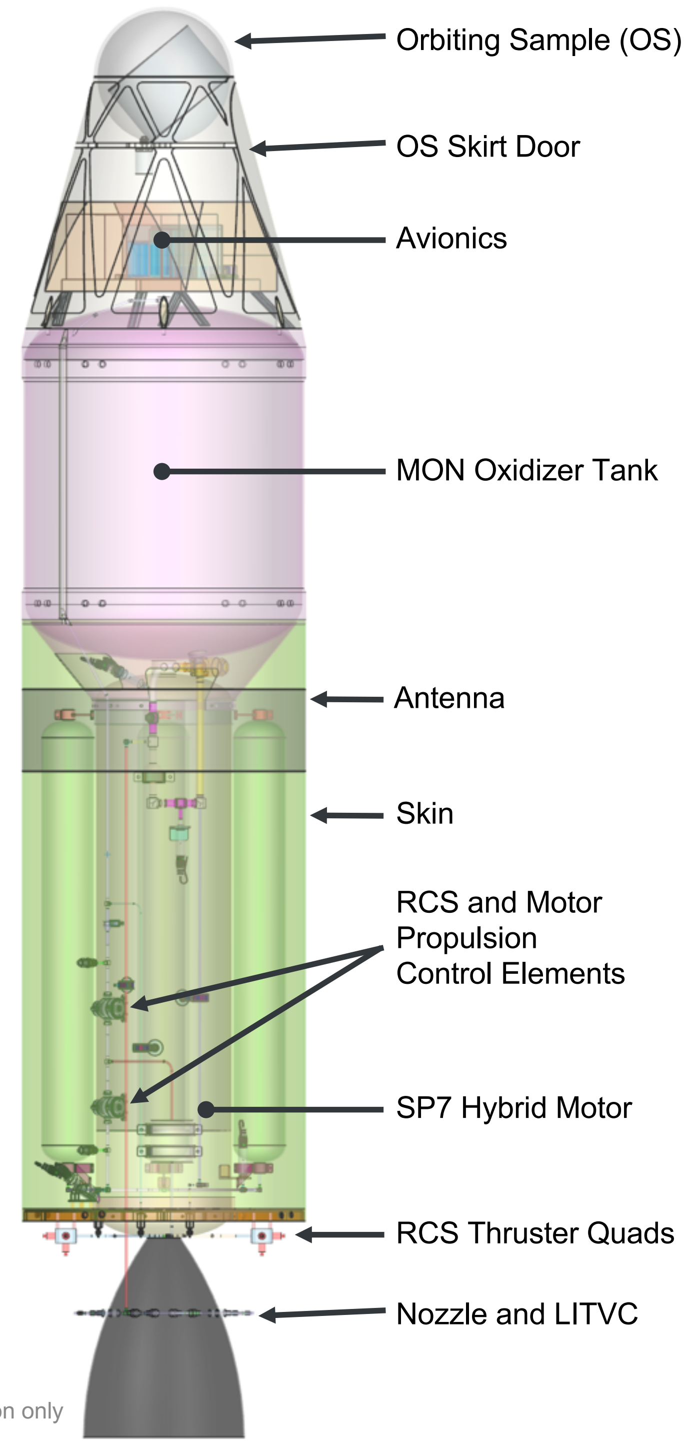


GLOM: Gross Liftoff Mass (CBE values shown)
AFT: Allowable Flight Temperature
SSTO: Single Stage to Orbit

Broad study of MAV architectures has led to the current Hybrid SSTO approach

MAV Reference Design

- Continued Study from 2015…
  - Added Subsystem Maturity and Fidelity
  - Validated Single-Stage-To-Orbit Design
    - Target Orbit 350 km @ 18º Inclination
    - 12 kg OS Capability (31-Tubes)
  - Length: 2.4 m x Diameter: 0.57 m
  - GLOM Range: 290-305 kg (w/ 50% margin)
    - Varies with launch uncertainties
  - Mass Fractions
    - Propulsion Dry Mass : 10%
    - Non-propulsion Dry Mass : 12%
    - Oxidizer Mass: 63%
    - Fuel Core Mass: 14%
    - Helium Mass: <1%



GLOM	Gross Liftoff Mass
LITVC	Liquid Injection Thrust Vector Control
OS	Orbiting Sample
RCS	Reaction Control System
TPS	Thermal Protection System

Hybrid MAV Technical Maturity

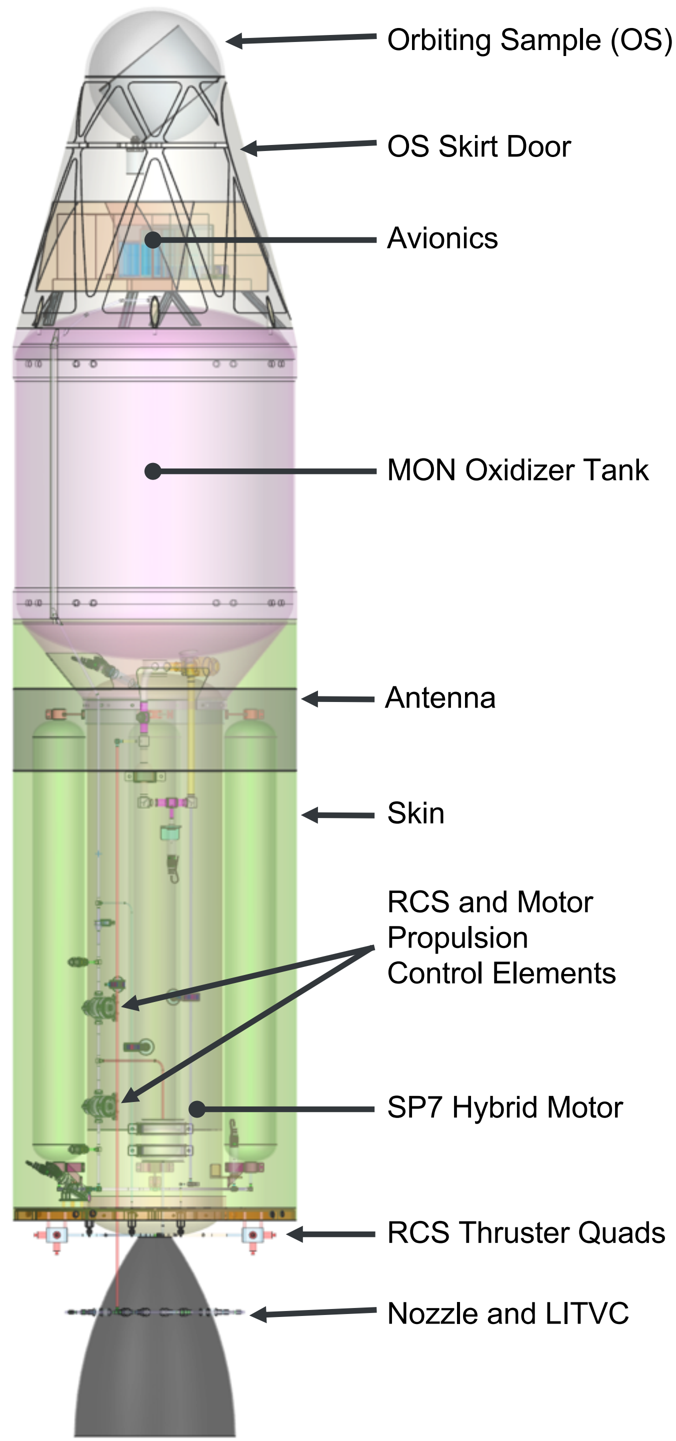
Subsystem	Maturity
OS	Significant Early Work and Prototyping Completed
Nose & Structure	Standard Flight Engineering
Avionics	Standard Flight Engineering
Prop Tanks	Standard Flight Tank Engineering
Prop Components	Valves and Regulators are Long Lead Developments
Hybrid Motor	Technology Development Underway
RCS Components	Standard Engineering
LITVC	Technology Development Underway

High Maturity

Advanced Engineering

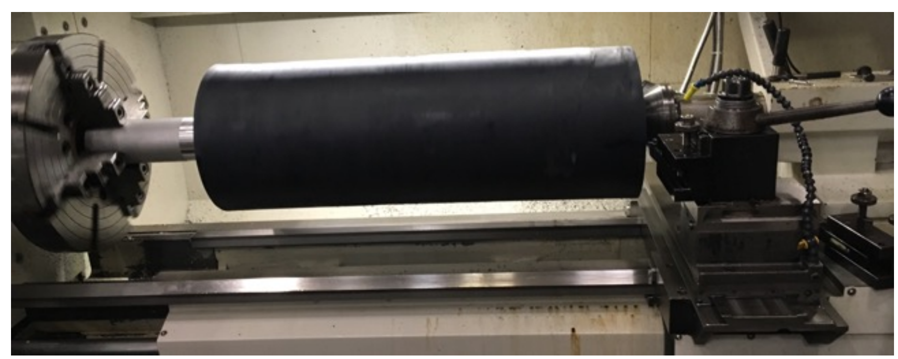
Technology Development

GLOM	Gross Liftoff Mass
LITVC	Liquid Injection Thrust Vector Control
OS	Orbiting Sample
RCS	Reaction Control System
TPS	Thermal Protection System



MSFC SP7 Fuel Grain Work

- MSFC has developed a robust and repeatable fuel grain manufacturing technique
  - Started making grain in many segments
  - Now capable of full-scale monolithic grains



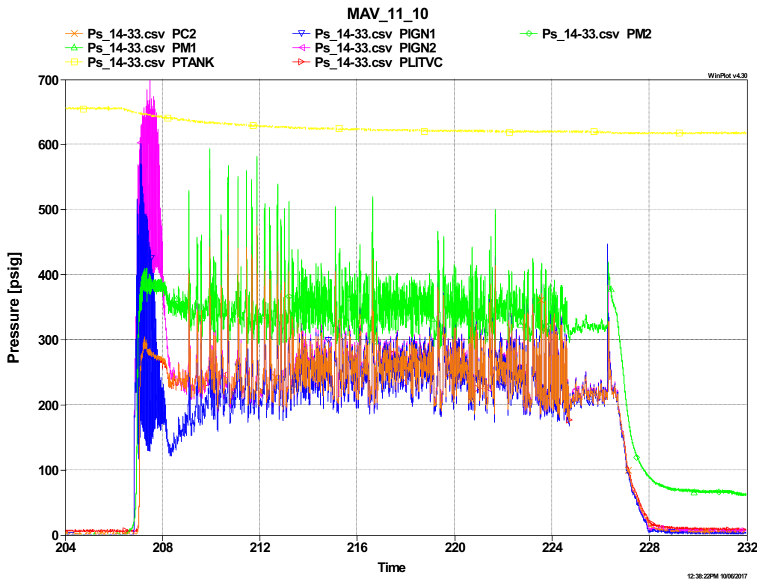
MAV Testing Progress - SPG

Complete ✓ Motor 1: Verify ignition of desired propellant combination at scale.

Complete ✓ Motor 2: Extend burn duration (>20 s) and work on stability

March 2018

- Motor 3/4: Burn fuel grain to completion, restart at similar conditions to 2nd burn on MAV, extend burn durations, reduce insulation mass, demonstrate LITVC
- Motor 5: Burn fuel grain to completion, extend burn durations
- Motor 6: Full duration burn with a restart (motor inspection between burn 1 and 2)
- Motor 7: Full duration burn with a restart (no outside intervention)



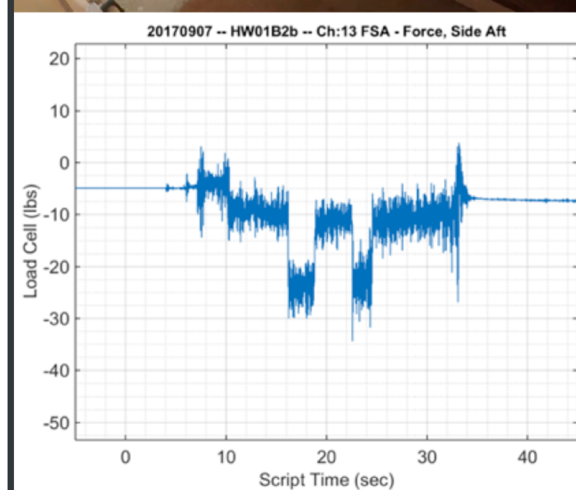
MAV Testing Progress – Whittinghill

Complete ✓ Heavy Weight Motor 1 (two burns):
- Smooth and rapid ignition
- Establish SP-7 regression rate at full scale
- Demonstrate smooth combustion
- Demonstrate high c* efficiency
- Obtain initial LITVC data

Complete ✓ Heavy Weight Motor 2:
- Burn motor on peak O/F
- Increase burn time (~60 sec)
- Demonstrate high c* efficiency with minimal system impact
- Investigate alternate injector patterns for more benign fuel impingement effects
- Continue acquiring LITVC data

Feb 2018 Flight Type Motor 3:
- Investigate lower injector deltaP for (flight) He conservation
- One burn, near full duration
- Continued LITVC

Apr 2018 Flight Type Motor 4:
- Full impulse for MAV mission
- C* efficiency > 0.95
- High Fuel utilization
- Remote re-start, 2 burns on a MAV mission profile.
- Continued LITVC



MAV Technology Development Status

OS Concept

Orbiting Sample (OS) Concept Overview

- The OS provides a container to securely hold and protect the M2020 Sample Tubes (nominally 31) for return to Earth
  - Mars atmospheric samples are also contained in the OS and returned to Earth
- Orbital Sample (OS) interfaces directly with both SRL/MAV and SRO elements of MSR
- The OS with Sample Tubes must withstand environments imposed by SRL, SRO, EEV

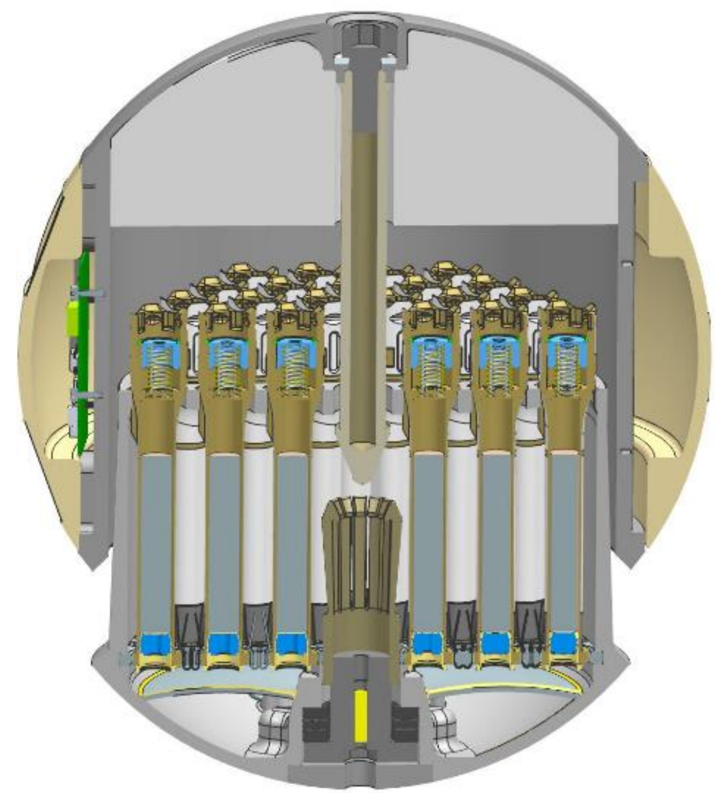
Current OS Reference Design

Mars 2020 Sample Tube Assembly

Engineering OS ready for impact testing

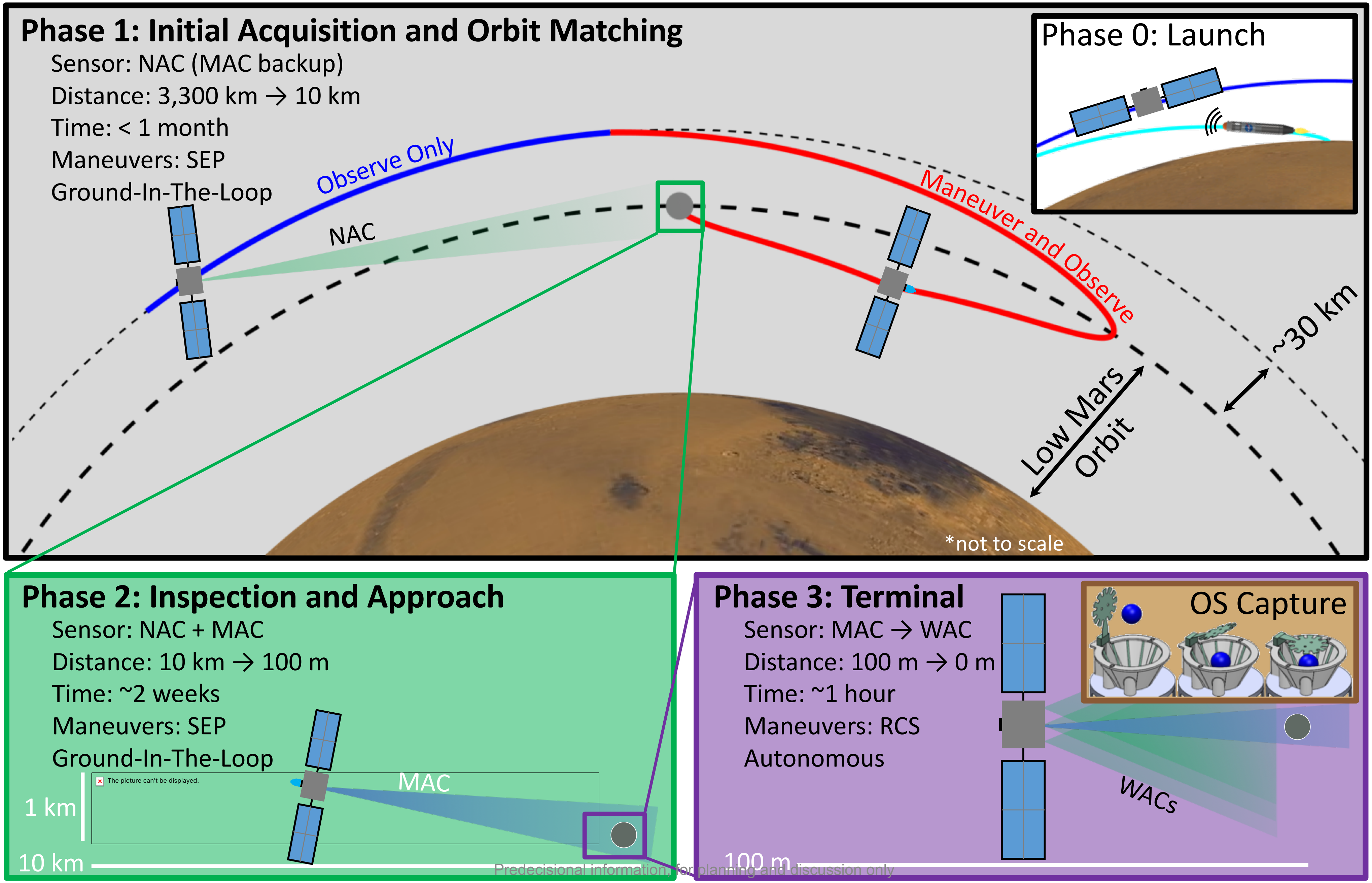
OS Architecture and Design Approach

- OS Concept
  - 31 tube slots, central rod for load support
  - 2 air sample tanks with manual valves
  - Assembled at Mars with aluminum foam to provide tube preload for EEV landing
- Surface
  - Sandblasted gold meets thermal, albedo, & specular reflectance requirements
- Mass & diameter
  - Mass ≤ 12 kg
  - Diameter ≤ 28 cm



Rendezvous Concept

Rendezvous Concept Overview



Rendezvous Concepts: MSR vs Earth-Orbit (e.g., ISS)

<table>
<tr><th></th><th>Long Range (>10 km)</th><th>Medium Range (10 km - 100 m)</th><th>Short Range (<100 m)</th></tr>
<tr><td rowspan="6">MSR Harder than ISS</td><td>Significant MAV Delivery Errors</td><td></td><td></td></tr>
<tr><td colspan="2">OS harder to image than ISS (smaller, farther from sun)</td><td></td></tr>
<tr><td colspan="2">No GPS Available</td><td></td></tr>
<tr><td colspan="2">No Ground Tracking</td><td></td></tr>
<tr><td colspan="3">Target is passive</td></tr>
<tr><td></td><td colspan="2">Round Trip Light Time ≈ Minutes</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="6">MSR Easier than ISS</td><td colspan="2">Orbit matching is allowed to take weeks</td><td></td></tr>
<tr><td colspan="3">Target shape is simple (sphere)</td></tr>
<tr><td colspan="3">Target surface properties known and can be tailored to rendezvous</td></tr>
<tr><td></td><td></td><td>Relative Attitude does not need to be controlled</td></tr>
<tr><td></td><td></td><td>Unconstrained approach vector</td></tr>
<tr><td></td><td></td><td>Abort options are less constrained</td></tr>
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Increases propellant required

Long range optical detection required

Increased autonomy required

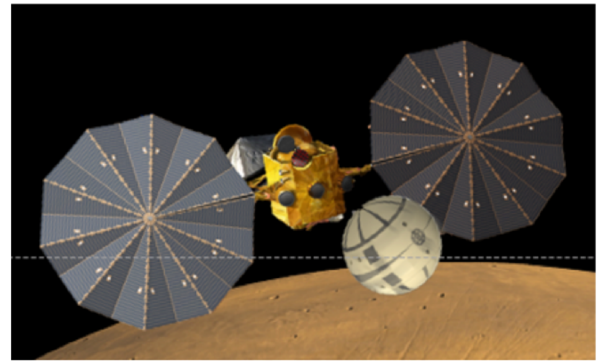
Reduces propellant and autonomy requirements

Complicated LIDAR/image processing not needed

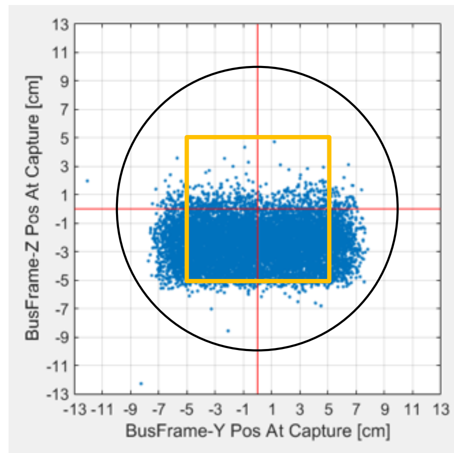
Safer and more straightforward rendezvous strategy

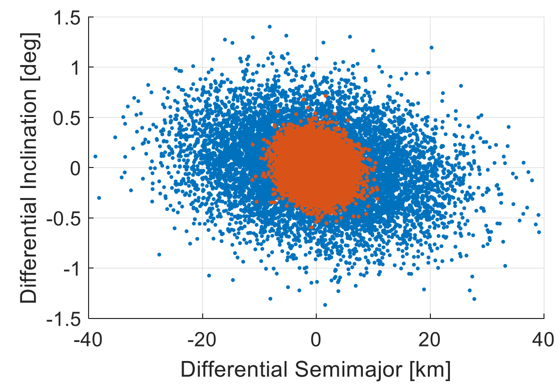
- Many commercial and international partners have experience with rendezvous at the ISS
- The main new challenges for a potential MSR:
  - Long range acquisition of the OS (this is done by GPS and ground sensing for ISS)
  - Completely autonomous terminal phase (round trip light time too high for human-in-the-loop)
- However, many aspects are easier:
  - Because the OS is a sphere, its attitude is not relevant for rendezvous
  - Because the OS is small, there are no “keep-out corridors” complicating the approach and abort vectors

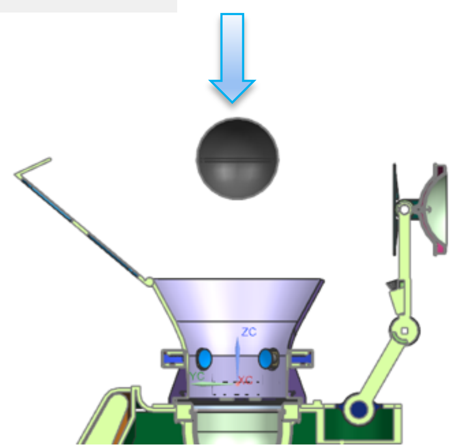
Driving Rendezvous Requirements



- OS:
  - Diffuse Sphere
  - Diameter = 28cm
  - Albedo: ≥ 0.3
- MAV Orbit:
  - Low Mars Orbit, circular
  - Unconstrained beta angle
  - Inclination: ±1° (3σ)
  - Semimajor axis: ±32 km (3σ)
- Capture Vector (3σ):
  - Position: ± 10 cm
  - Velocity: 5 ± 1 cm/s
  - Direction: ± 5°
- System Considerations:
  - Remain fail-safe until terminal phase
  - Single-Fault Tolerance



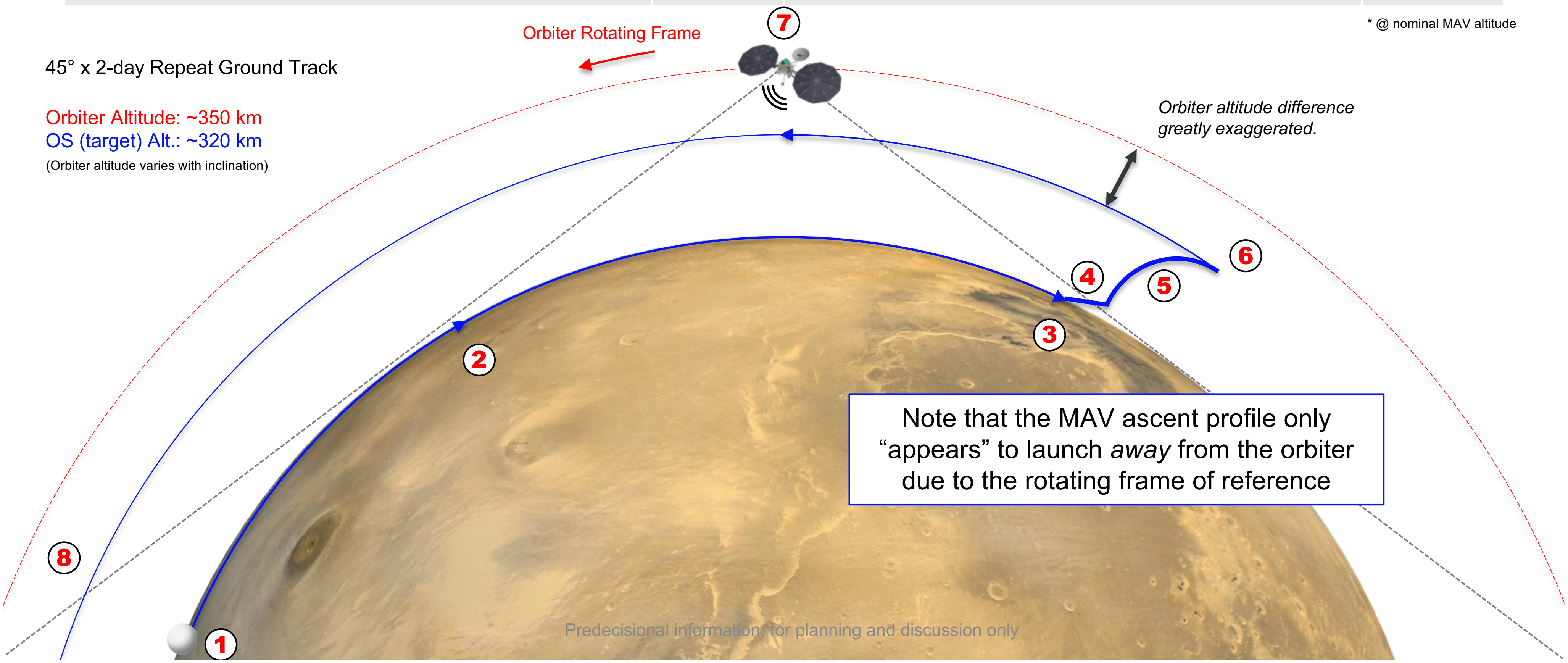




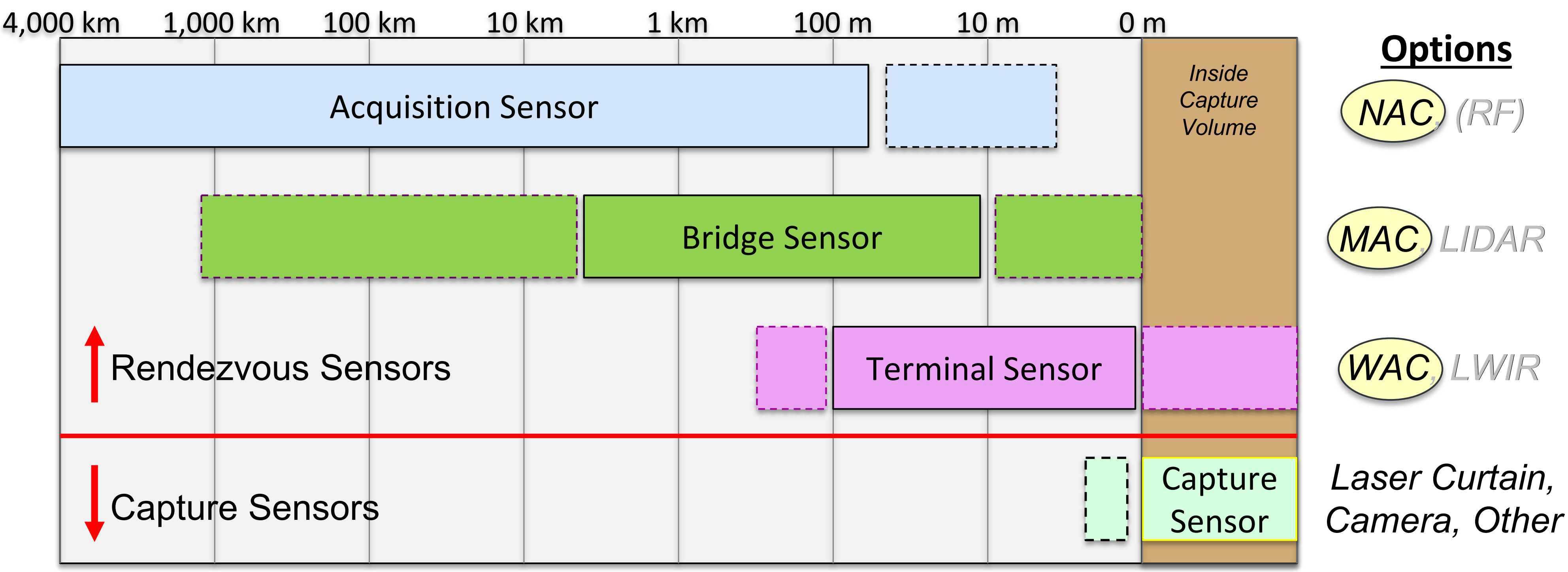
Notional MAV Launch Sequence

Event	Time	Event	Time
(1) MAV Ready for Launch	L-2d	(5) Ascent Coast Phase	L+15m
(2) MAV-Orbiter In-View (Go / No Go)	L-20m	(6) 2nd Burn / OS Separation	L+16m
(3) MAV Launch	L-0	(7) OS Passes under Orbiter	L+15h*
(4) Ascent 1st Burn	L+2m	(8) OS Occulted by Mars	L+39h*

* @ nominal MAV altitude



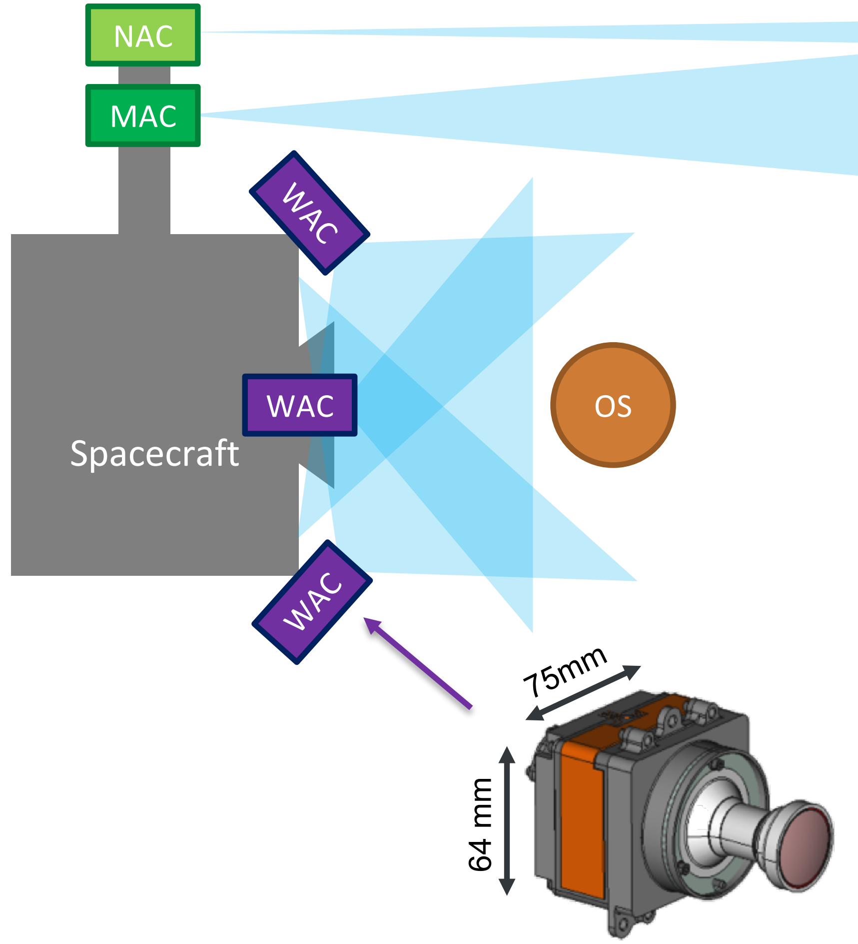
Rendezvous Sensor Domains



Sensor	Max Range	Min Range	FOV	Aperture	Detector	Accuracy	Phase Angle
NAC Narrow Angle Camera	>3,500 km	10 – 50 m	5° – 8°	5 – 10 cm	Existing	<35 µrad	< 90°
MAC Medium Angle Camera	>1,000 km	1 – 10 m	10° – 60°	3 – 5 cm	Existing	<500 µrad	< 90°
LIDAR	1 – 10 km	1 – 10 m	~20°	~5 cm	Existing	~3 mrad Range: ~10 cm	All
WAC Wide Angle Camera	100 m – 1 km	0 – 1 m	60° – 120°	1 – 5 cm	Existing	~1 mrad	< 90°
LWIR Long Wave Infrared	200 m – 2 km	0 – 1 m	60° – 120°	2 – 5 cm	Existing	~3 mrad	All

Reference Sensor Suite

- **Narrow Angle Camera**
  - Provides initial detection of OS at max. range (~3,500 km)
- **Medium Angle Camera**
  - Maintains visual lock during approach, provides relative navigation information
  - Can detect OS at long range (>1,000 km) in case NAC fails
- **Wide Angle Cameras**
  - Stereoscopic view of the OS at terminal approach, and covers a wide swatch of sky to provide situational awareness



Mars2020 EECAM

<u>Example Hardware:</u>

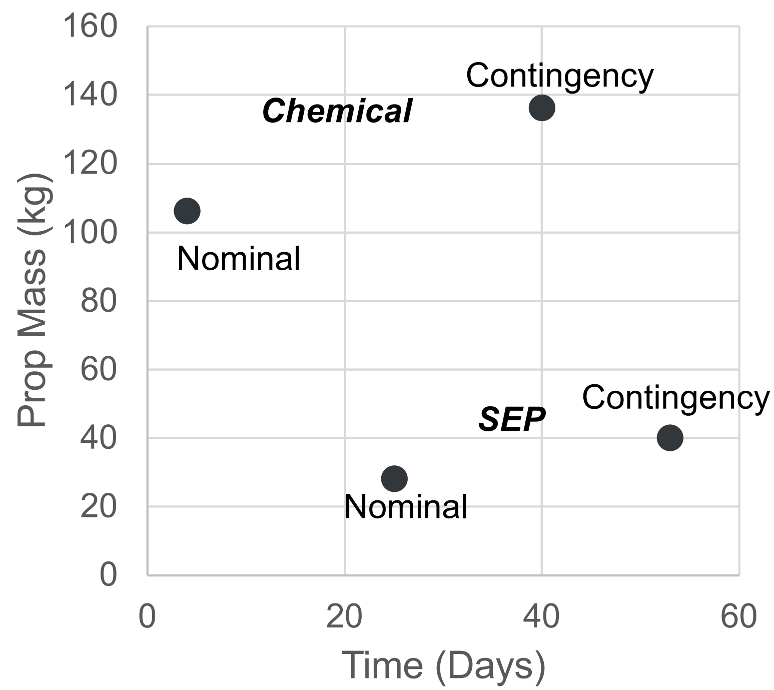
- WAC = M2020 EECAM Build-to-Print
- NAC and MAC use EECAM detector and electronics, but with larger optics
- All 5 cameras: ~10kg, 15W

SEP vs Chemical Orbit Matching

		3σ Values Nominal Ops			3σ Values Contigency Ops		
Propulsion Option	Isp [sec]	Time [days]	Delta V [m/s]	Propellant [kg]	Time [days]	Delta V [m/s]	Propellant [kg]
Chemical	230	4	78	106	40	100	136
SEP	2600	25	233	28	53	341	40

(Contingency scenario corresponds to failure to detect OS prior to first occulation, requiring 10-day limb-scanning period)

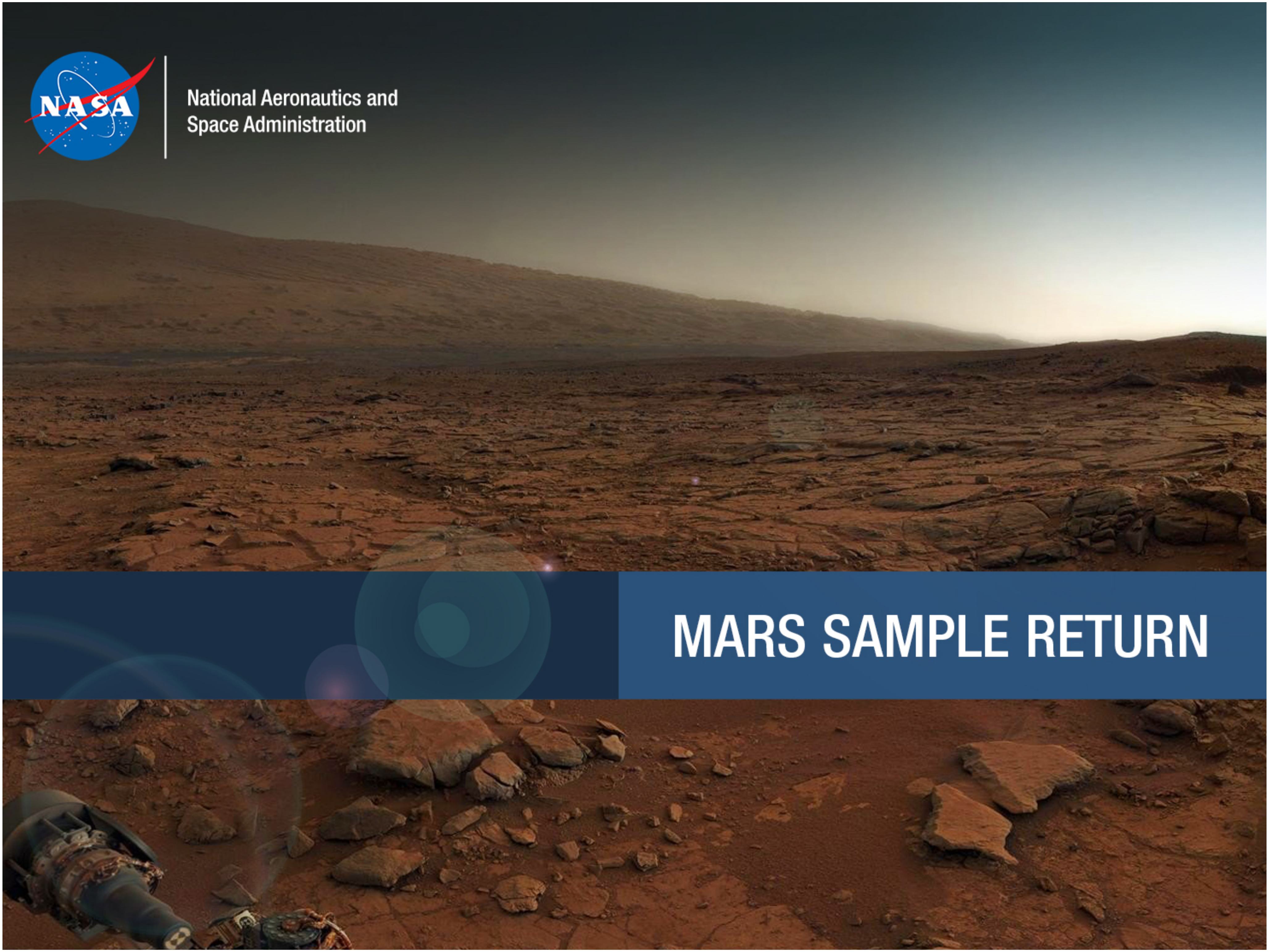
- Both Chemical and SEP propulsion options can meet MSR orbit matching needs for OS Rendezvous
  - Note: SEP case corresponds to high-acceleration SEP configuration, consistent with a fast-return MSR orbiter optimized for speed
- Key trade is between time-to-complete vs. propellant mass
  - SEP takes longer, but has a significantly lower propellant cost than Chemical



Conclusion

- Extensive MAV trade studies have established a Hybrid Propulsion, Single-Stage-to-Orbit MAV reference design for potential MSR
  - JPL/MSFC team working with industry partners to fully mature MAV technology to TRL 6 by 2022
- The Orbiting Sample (OS) – the physical interface between MAV and SRO – has a mature conceptual design
  - Fully incorporates M2020 sample tube design
- The SRO-OS Rendezvous function is well understood
  - Simple passive-imaging sensor suite is fully capable of supporting OS detection, approach, and terminal rendezvous phases

Key MSR technologies are on track to support SRL/SRO launch as early as 2026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