Mars Sample Return
Sample Retrieval Lander (SRL) and Earth Entry Vehicle (EEV)

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NASA Langley/Ames EDL Seminar Series
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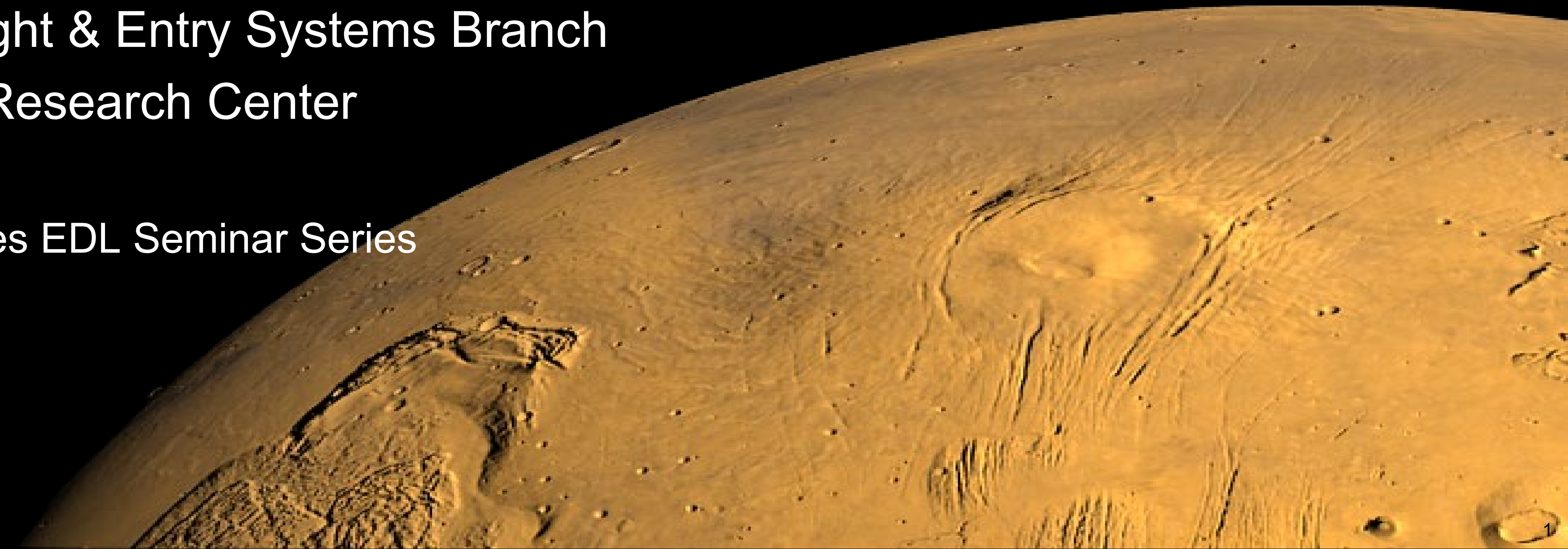


Outline

- Mars Sample Return (MSR) Overview
- Sample Retrieval Lander (SRL), K. Edquist
- Earth Entry Vehicle (EEV), J. Corliss
- Q&A

MSR Campaign Elements

- The purpose of the MSR flight elements (SRL, ERO) is to acquire and return to Earth a scientifically-selected set of Mars samples for investigation
- The purpose of SRL is to deliver the Sample Fetch Rover (SFR), Mars Ascent Vehicle (MAV), and Orbiting Sample (OS) container with pin-point accuracy near samples collected and left by the Mars 2020 Perseverance rover
- The purpose of ERO is to bring the samples and EEV back to Earth for EDL ending in the Utah Test and Training Range (UTTR)

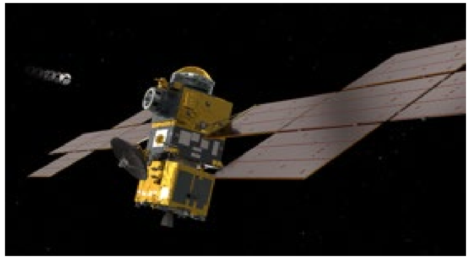
Focus of Presentation

Sample Caching Rover (Mars 2020) Operations

- *Sample acquisition/caching*
- *Sample (subset) delivery*

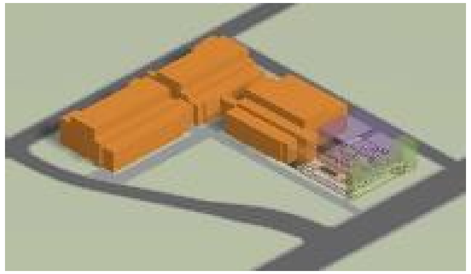
Sample Retrieval Lander (SRL)

- *Sample Fetch Rover (SFR)*
- *Orbiting Sample (OS) container*
- *Mars Ascent Vehicle (MAV)*



Earth Return Orbiter (ERO)

- *Capture/Containment System*
- *Earth Return Vehicle (EEV)*

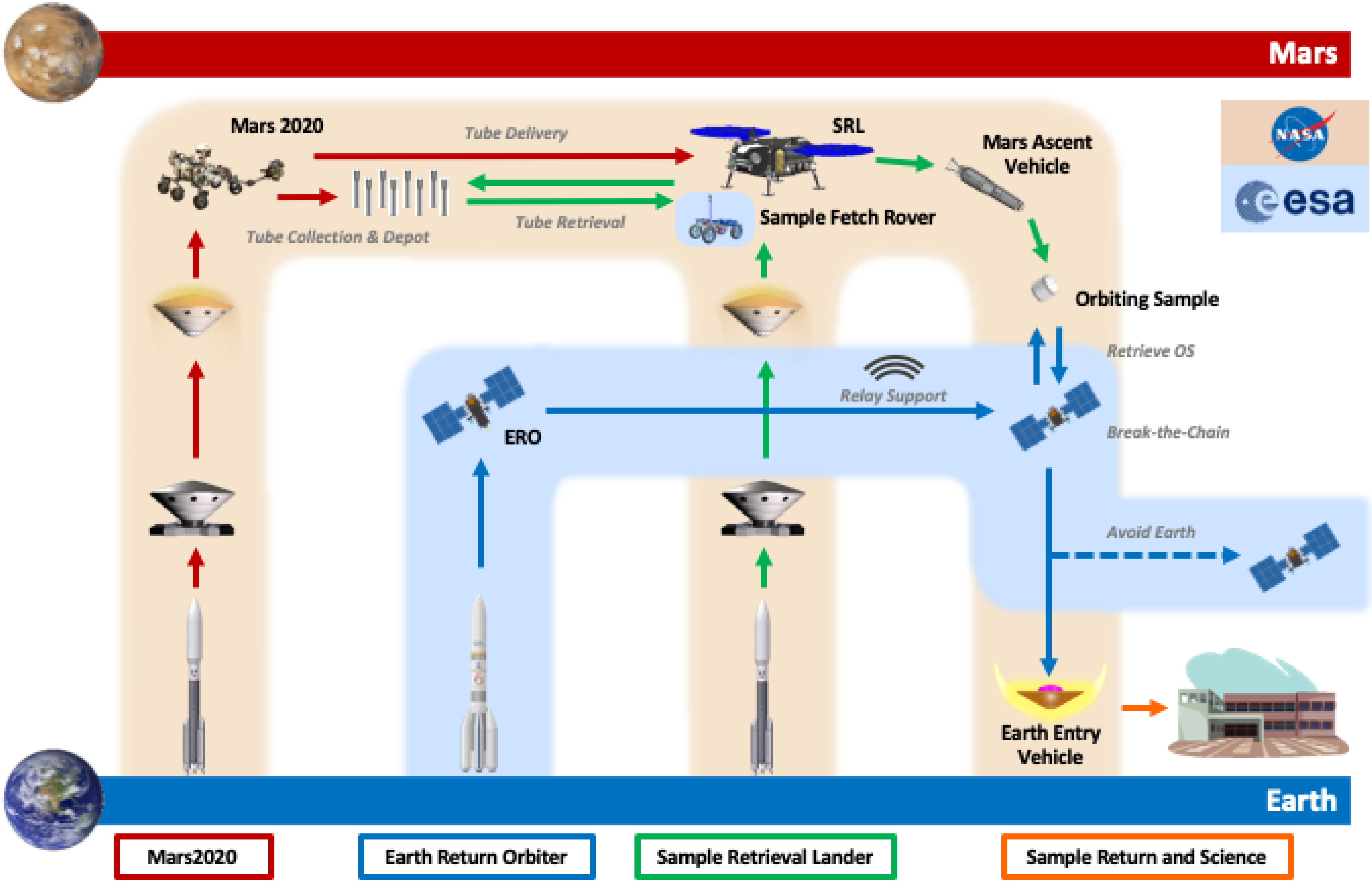


Mars Returned Sample Handling (MRSH)

- *Sample Receiving Facility*
- *Curation*
- *Sample investigations*

MSR Campaign Overview (from AAS 20-106)

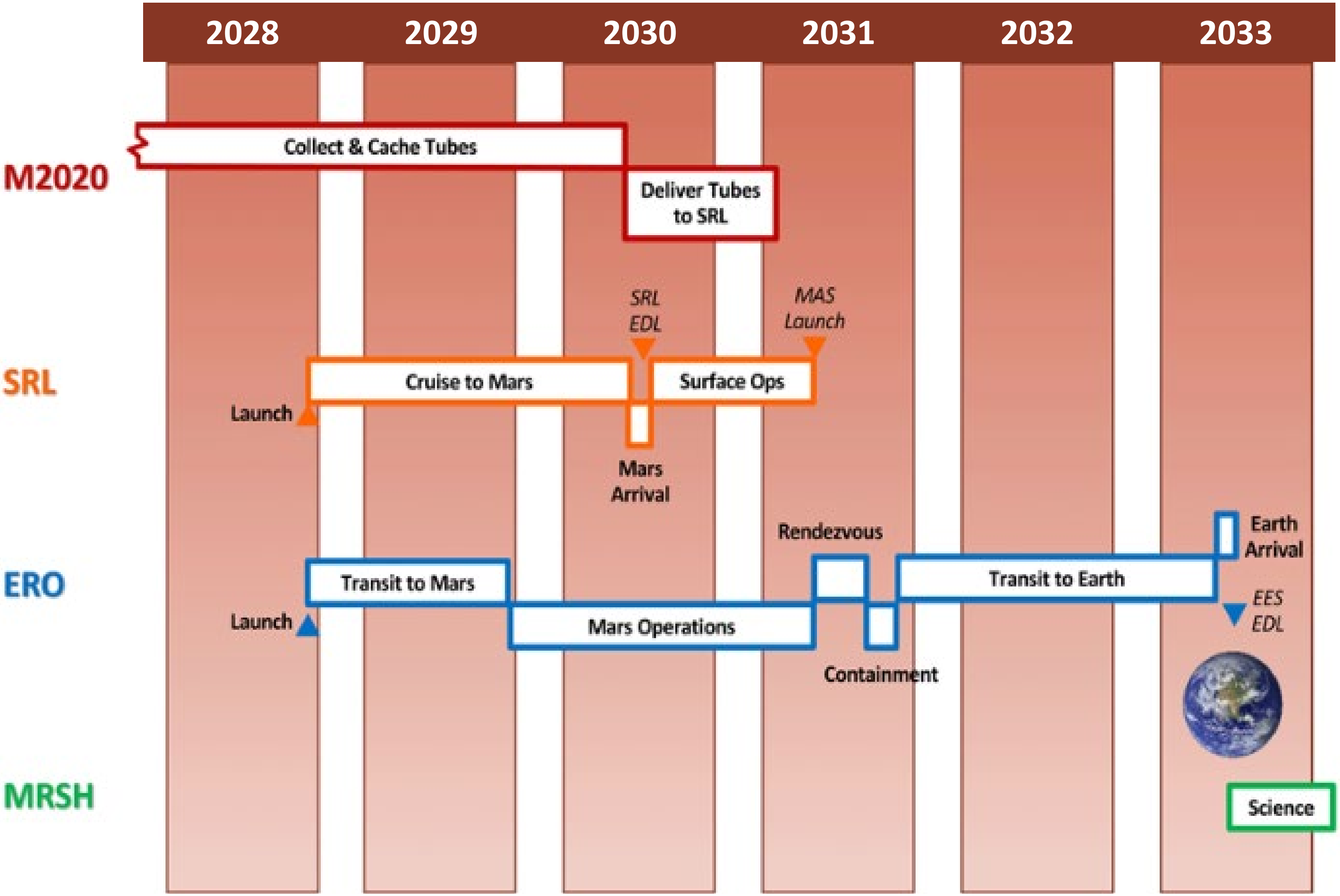
- Mission scenarios are being developed for sample return to Earth approximately 5 years after SRL launch
- The Sample Fetch Rover (SFR) and Earth Return Orbiter (ERO) spacecraft are provided by ESA, all other elements are provided by JPL/NASA and contractors



M. Ivanov and S. Sell, "Challenges of Mars Sample Return Entry, Descent, and Landing," AAS 20-106, Annual AAS Guidance, Navigation and Control Conference, January 2020

MSR Campaign Notional Timeline (from AAS 20-106)

- SRL launch was originally planned for 2026, but multiple challenges (cost, schedule, technical) will result in launch no earlier than 2028



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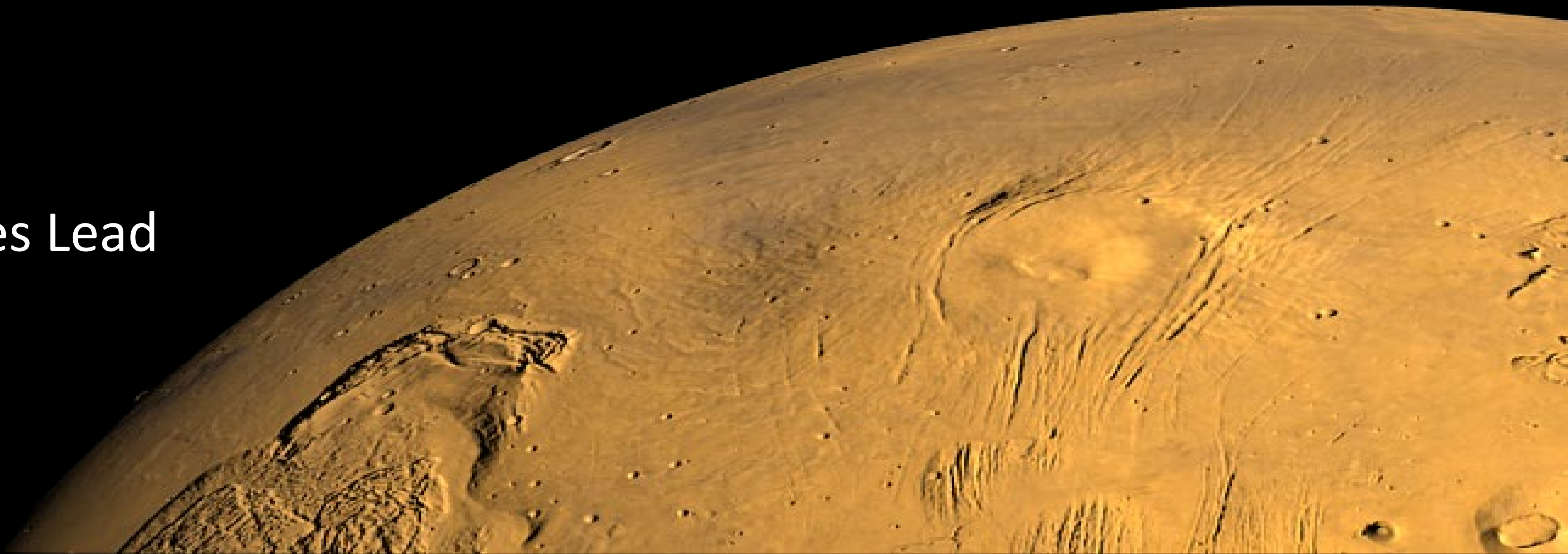
Sample Retrieval Lander (SRL)



Karl Edquist

SRL Aerosciences Lead

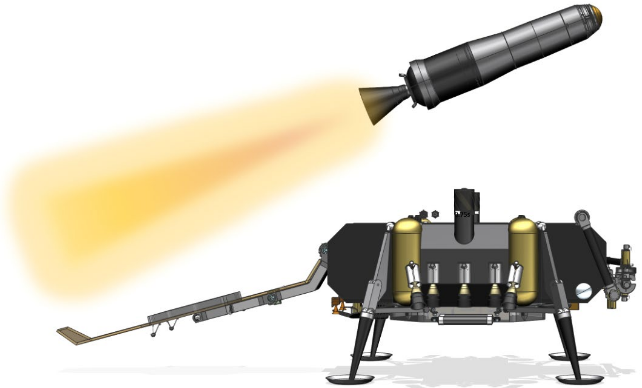
SRL Entry, Descent, and Landing (EDL) Roles

- Jet Propulsion Laboratory (JPL), Pasadena, CA
  - MSR project management
  - Flight system lead
  - EDL phase lead
  - Lead for numerous sub-systems: mechanical, thermal, telecommunications, etc.
- NASA Langley Research Center (LaRC), Hampton, VA
  - Flight mechanics, aerodynamics, aeroheating, engineering instrumentation
- NASA Ames Research Center (ARC), Moffett Field, CA
  - Aeroheating, thermal protection system (TPS), engineering instrumentation

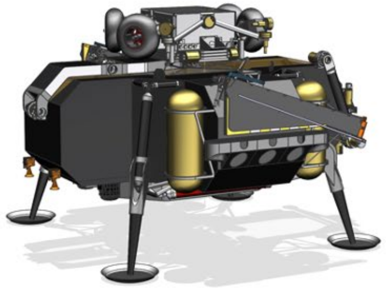
SRL Current Status

- The SRL flight project currently is in Phase A – Preliminary Analysis
  - Launch is no earlier than 2028
- The project currently is considering whether to deliver the Sample Fetch Rover (SFR) and Mars Ascent Vehicle (MAV) in one or two launches
  - One launch: SFR + MAV in one capsule, entry system larger and much heavier than any past Mars mission, parachute larger than any past mission, may require using new flight system elements
  - Two launches: Entry system heavier than MSL and Mars 2020, probably no new technologies needed, but more costly
- A decision on one or two launches is expected in the next few months

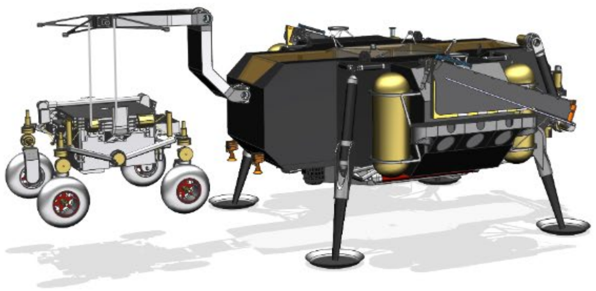
MAV



SRL



SFR



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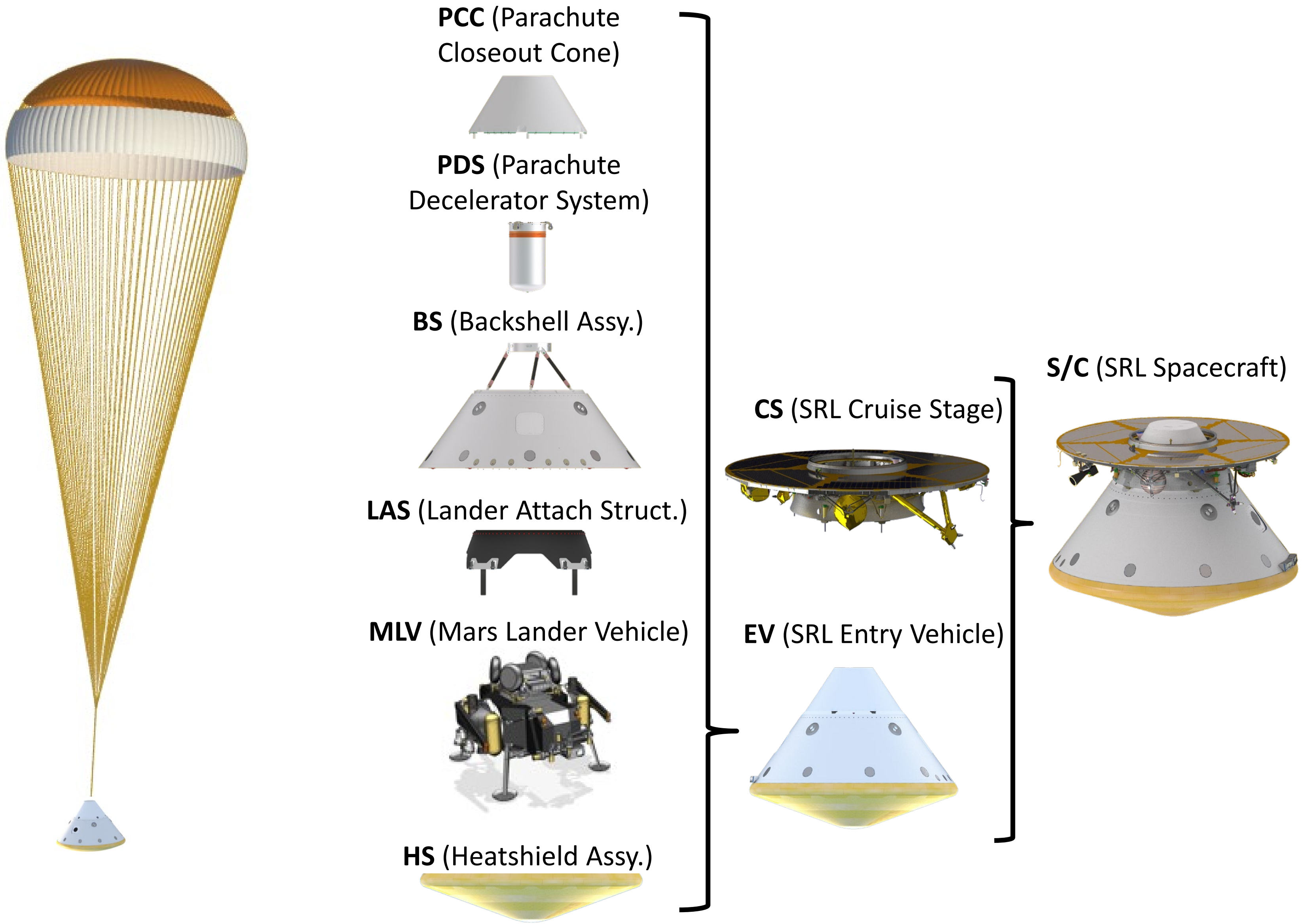
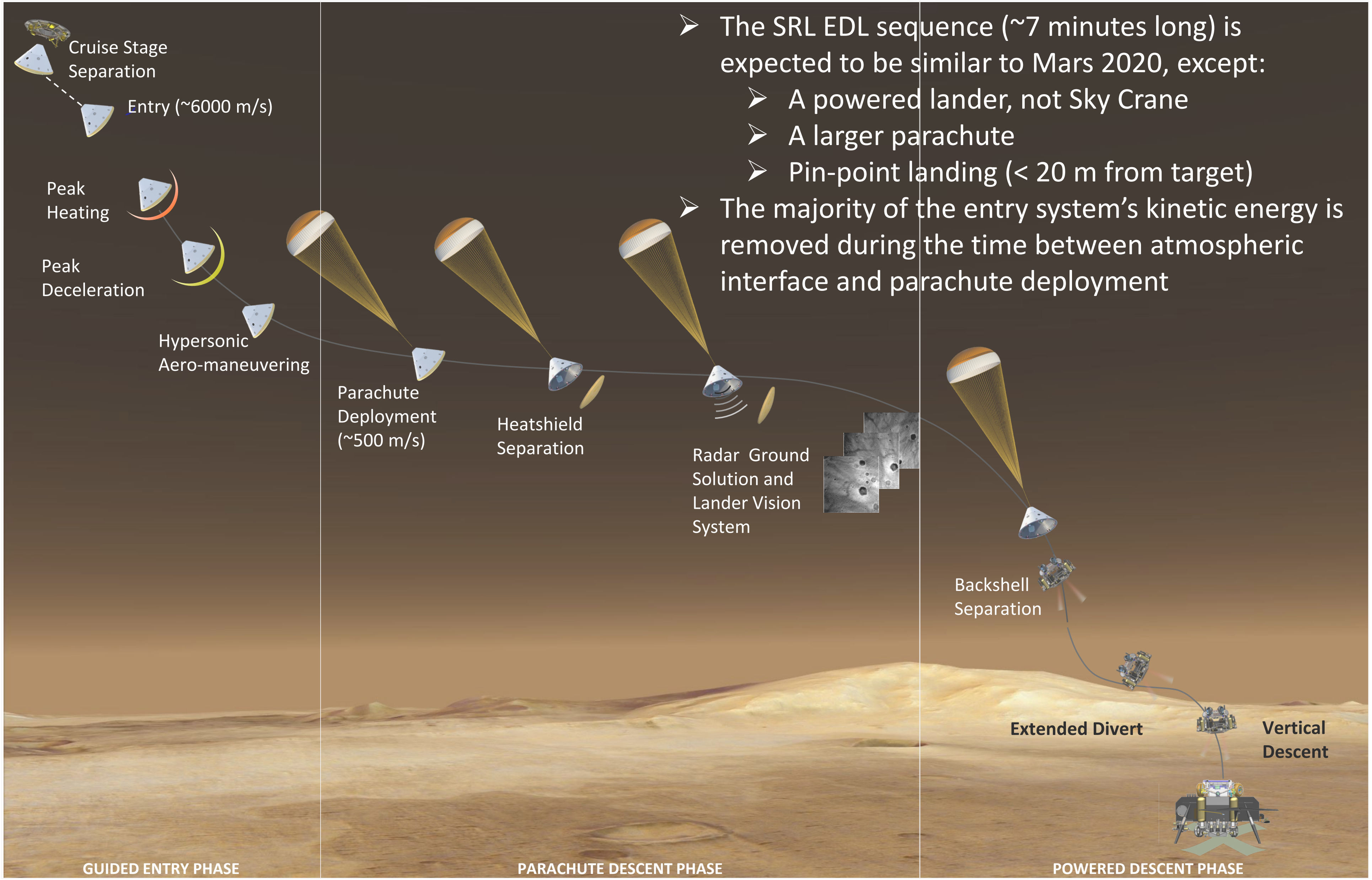
SRL Baseline Entry System



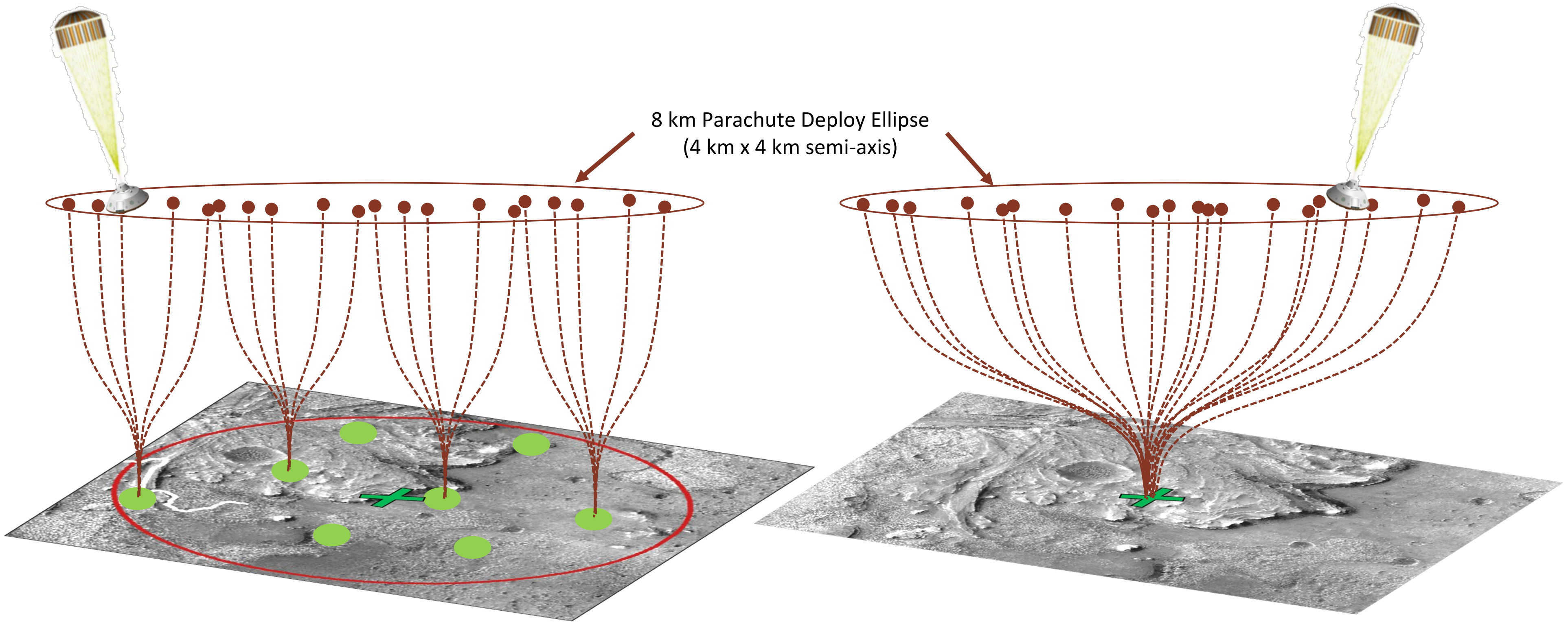
SRL EDL Notional Sequence

- The SRL EDL sequence (~7 minutes long) is expected to be similar to Mars 2020, except:
  - A powered lander, not Sky Crane
  - A larger parachute
  - Pin-point landing (< 20 m from target)
- The majority of the entry system's kinetic energy is removed during the time between atmospheric interface and parachute deployment



SRL Pinpoint Landing (from M. Ivanov, JPL)

- The Entry Guidance phase delivers the spacecraft to an 8 x 8 km parachute deploy ellipse (same as Mars 2020)
- Powered Descent flies the spacecraft from that ellipse to the ground
  - Mars 2020: Flies to safest spot within divert capability (~650 m)
  - SRL: With 4 km of divert capability, can fly to a single point chosen prior to landing with cm-level accuracy from Perseverance imagery



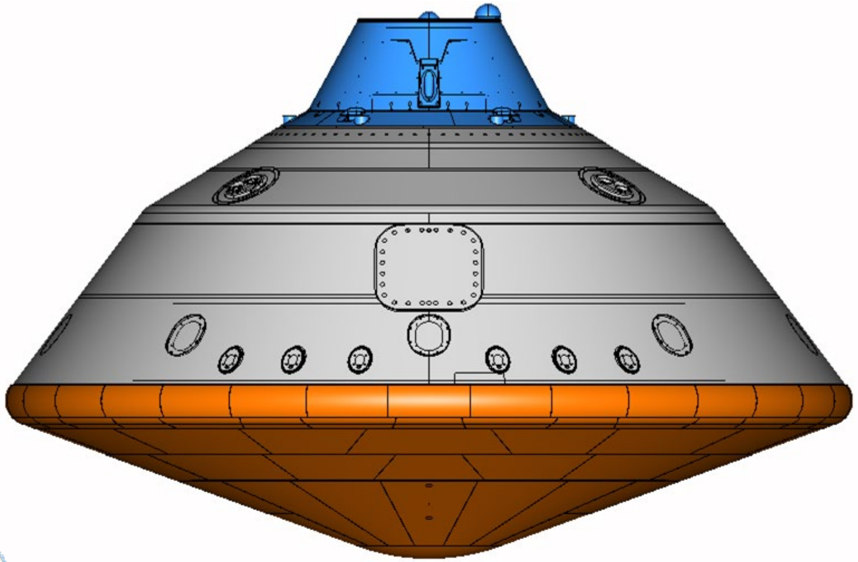
Mars 2020 divert to safest spot within divert capability

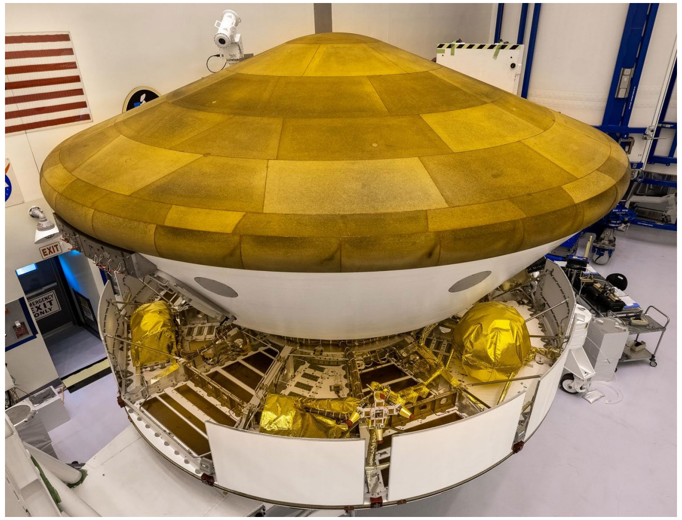
SRL 4 km divert capability allows divert to a single point

SRL Capsule Configurations Under Consideration

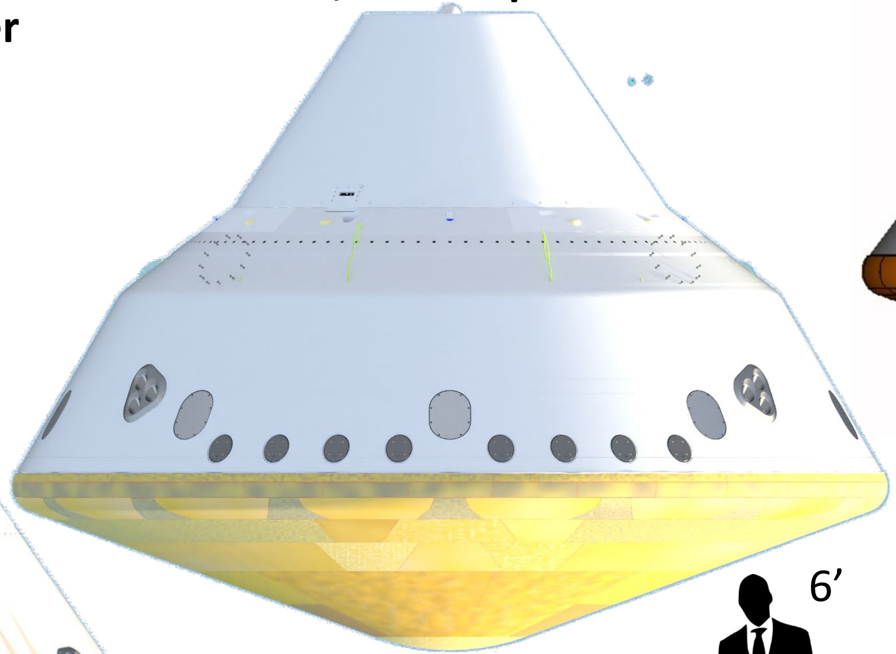
- A capsule diameter > 4.65-m may lead to a new launch vehicle fairing, re-thinking facility processing, and new transportation challenges

Mars 2020, 4.5-m
Shown for reference

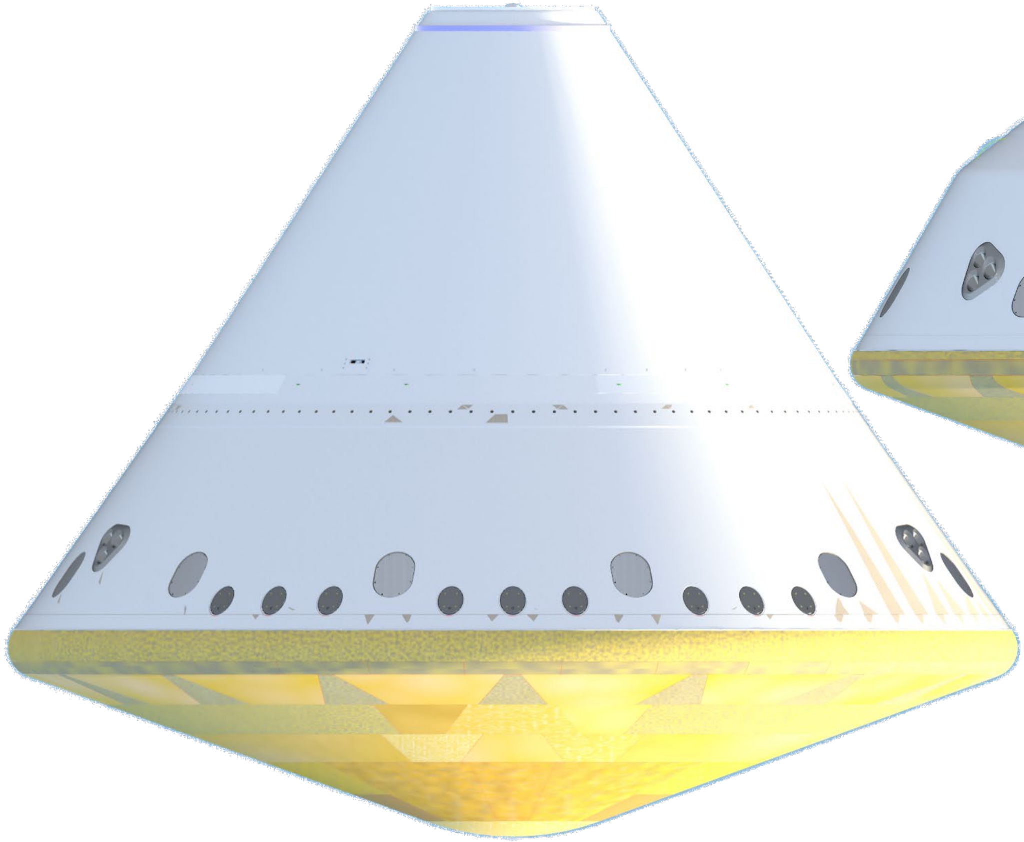


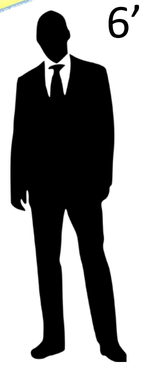


SRL Dual Launch, 4.65-m
SFR, MAV separate



SRL Single Launch, 5.5-m Diameter
SFR, MAV together





Comparisons to MSL and Mars 2020

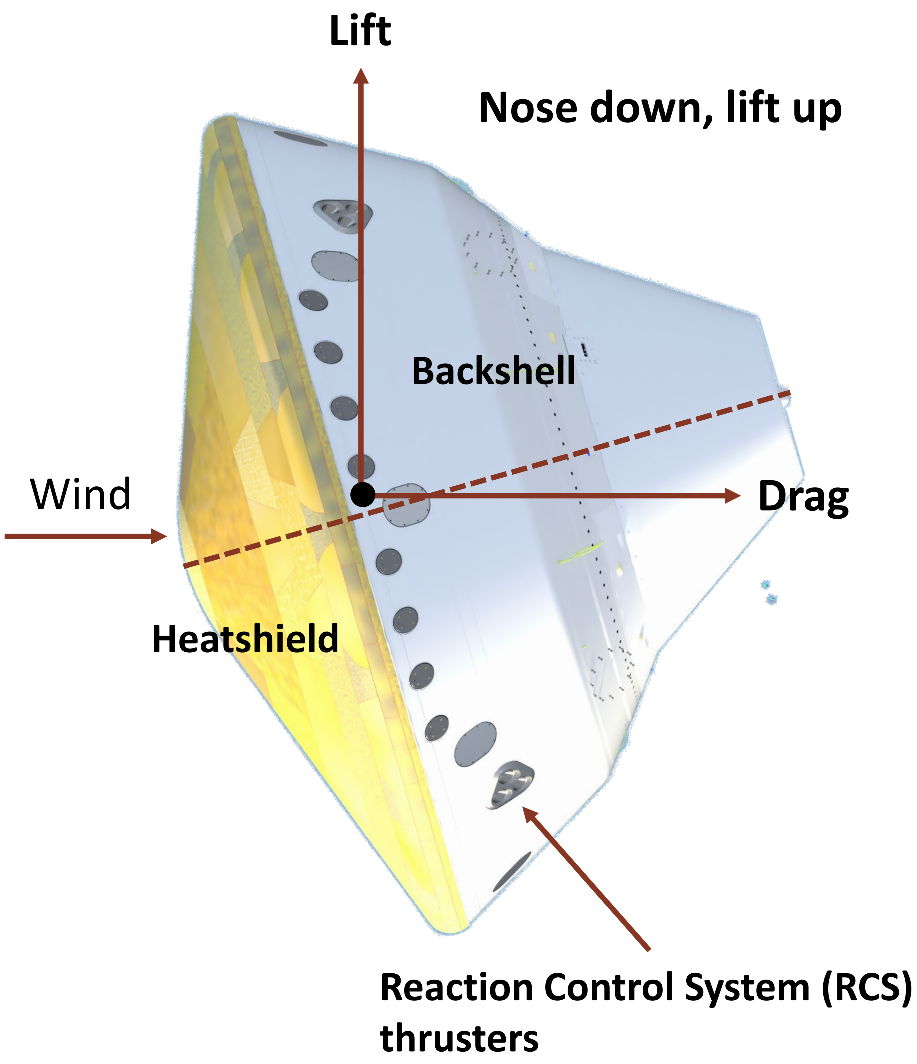
- SRL entry system mass/size are significantly higher than MSL and Mars 2020
  - Dual-launch lander wet mass > total entry system mass for MSL and Mars 2020

	Mars Science Laboratory (MSL)	Mars 2020	SRL (dual launch)	SRL (single launch)
Capsule diameter (m)	4.5	4.5	4.65	>5.4
Entry mass (kg)	3150	3360	>5000	>7500
Capsule ballistic coefficient (kg/m^2)	132	141	>200	>220
Parachute diameter (m)	21.35	21.5	~23	~26
Lander mass (wet) (kg)	1950	2090	>3000	>4000

- Higher mass leads to:
  - Higher ballistic coefficient = $m/(C_D A)$, m = mass, C_D = drag coefficient, A = projected heatshield area
  - Higher aerodynamic (structural) loads
  - Higher aeroheating (temperature) loads
  - Larger parachute with higher structural loads
  - More propellant
  - Less time/altitude margin to go through the EDL sequence of events
  - ...

SRL Entry Capsule Overview

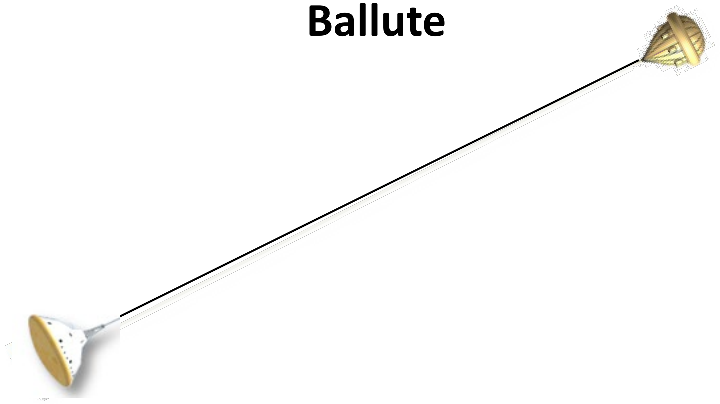
- The main requirements of the entry capsule are to:
  - Provide aerodynamic drag to decelerate the system
  - Provide aerodynamic lift to help steer the capsule via banking
  - Remain stable (heatshield forward, no large extremes in angle of attack)
  - Protect the payload from aerodynamic and aeroheating loads
- A lift-to-drag-ratio (L/D) of 0.24 was achieved for MSL and Mars 2020 by offsetting the center of mass a few inches to fly the capsule at an angle of attack near 16-deg
- The main EDL challenges for SRL are due to the higher entry system mass, especially for a single launch mission
  - A larger diameter capsule will be needed for more aerodynamic drag force
  - A higher angle of attack may be needed to generate more lift, which would require more ballast mass or a trim tab and may expose the backshell to more aeroheating



Other EDL Technologies Under Consideration for SRL

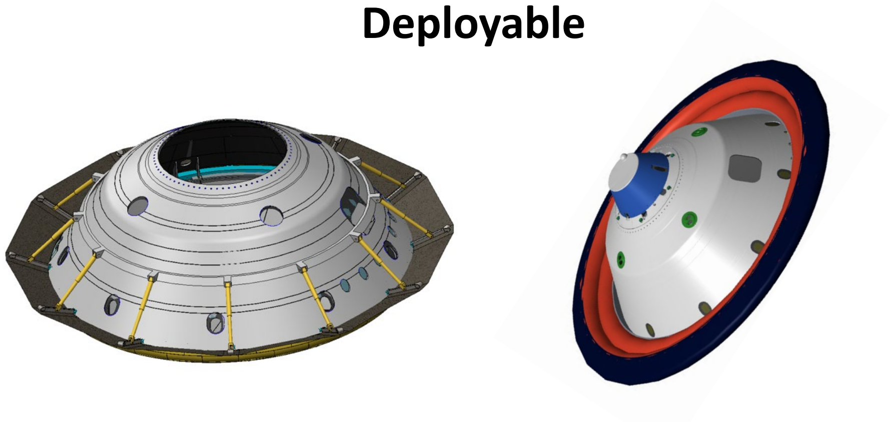
- One over-arching goal of EDL is to determine the right combination of capsule size, parachute size, parachute deployment Mach number, and propellant to land softly with the desired precision
- It is always desirable to have an entry system that is in family with previous missions, "if it ain't broke, don't fix it"
  - There are small windows to increase the SRL capsule and parachute diameters beyond Mars 2020 (4.5-m and 21.5-m, respectively), but new testing may be required
- If the SRL landed mass increases significantly beyond that of Mars 2020, then technologies that have not been used at Mars will need to be considered
  - Ballute: provides extra drag, helps deploy a very large parachute
  - Trim tab: provides higher angle of attack = more aerodynamic lift without having to shift the center of mass
  - Deployable: stowed at launch, deployed prior to entry, provides more drag

Ballute



Trim tab

Deployable

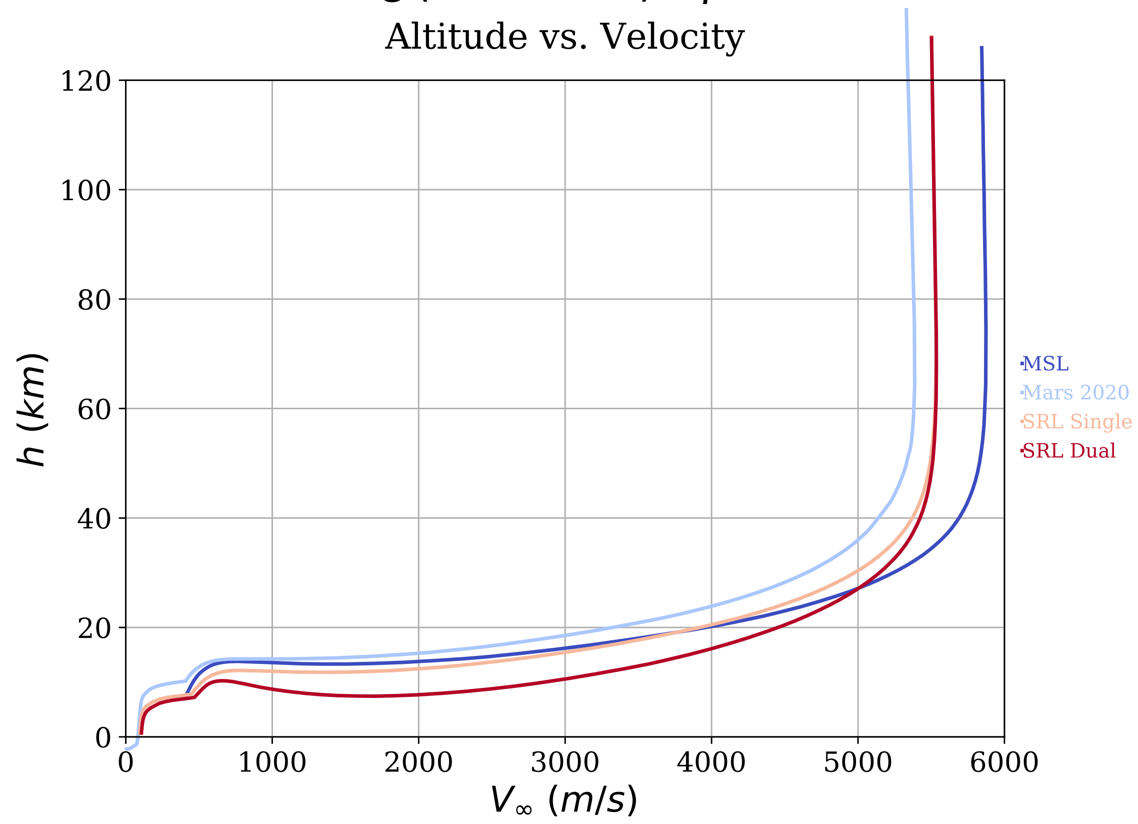


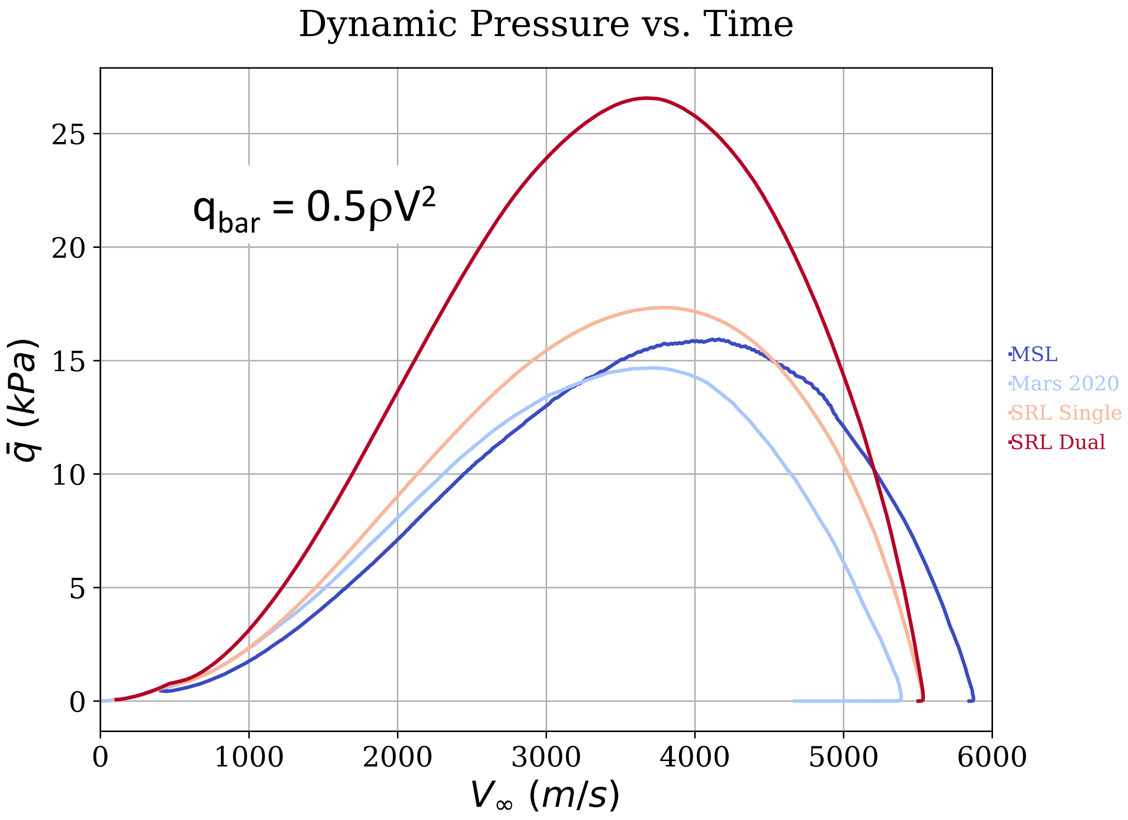
SRL Flight Mechanics Overview

- The flight mechanics (FM) team is responsible for designing, analyzing, and simulating the EDL sequence of events via mathematical models from numerous subject matter experts in the areas of:
  - The Mars environment (atmospheric density/temperature/winds/dust, gravity, planet rotation, terrain, etc.)
  - The entry system (mass properties, aerodynamics, aeroheating, parachute, propulsion system, guidance & navigation sensors, etc.)
- The FM team must analyze and test the entry system without a full end-to-end Earth test
- The main challenge of SRL FM team will be to manage the EDL sequence of events and to provide sufficient time and altitude for a very heavy entry system in the presence of numerous uncertainties in the Mars environment and entry system
  - Lots of attention will be spent on managing parachute loads and timeline/altitude margins i.e., time allocated to complete a particular EDL event

Sample SRL Trajectories

- The SRL entry system's high mass means that the capsule will maintain its speed for a longer time and will fly at higher speeds (V) for a given altitude (given atmospheric density, ρ), compared to MSL and Mars 2020
- Rules of thumb:
  - Aerodynamic loads ~ ρV^2
  - Aeroheating (convective) ~ $\rho^{1/2} V^3$





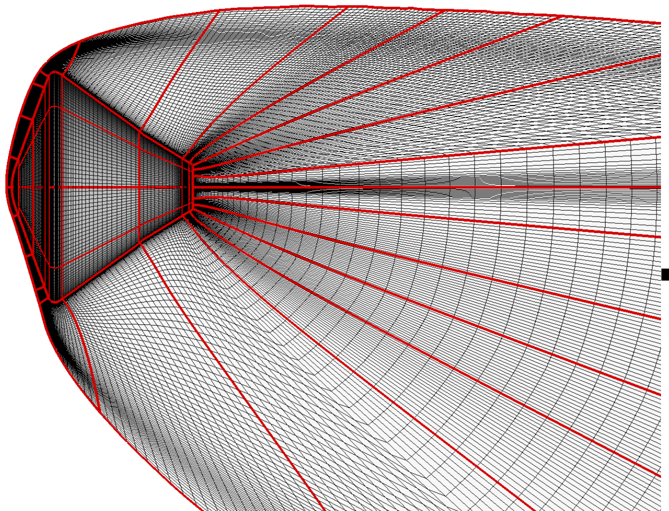
The Role of Computational Fluid Dynamics (CFD)

- The Mars environment (mostly CO_2, a little bit of N_2) during entry cannot be duplicated in any ground facility due to the extremely high speeds (up to ~6000 m/s) and resulting high temperatures (> 5000 K) surrounding the capsule
- CFD, which involves solving the fluid dynamic equations of motion on a computational grid of the capsule, allows us to simulate the entry environment and predict both aerodynamics and aeroheating in a single solution
- For aerodynamics, the CFD provides static aerodynamic coefficients (lift, drag, etc.)
- For aeroheating/TPS, the CFD provides the inputs necessary to analyze and test the TPS material responses to the predicted environments

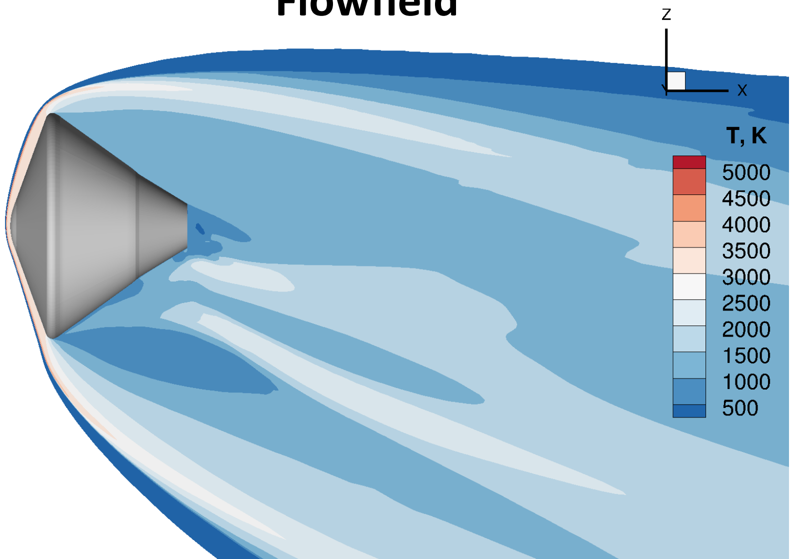
CFD Inputs:
1. Capsule geometry
2. Mars conditions
3. CFD parameters

CFD Outputs (surface):
1. Pressure
2. Temperature
3. Shear stress
4. Convective heat flux
5. Radiative heat flux
6. …

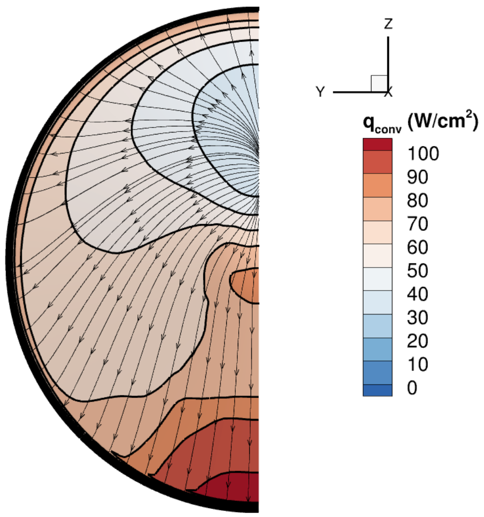
Grid



Flowfield



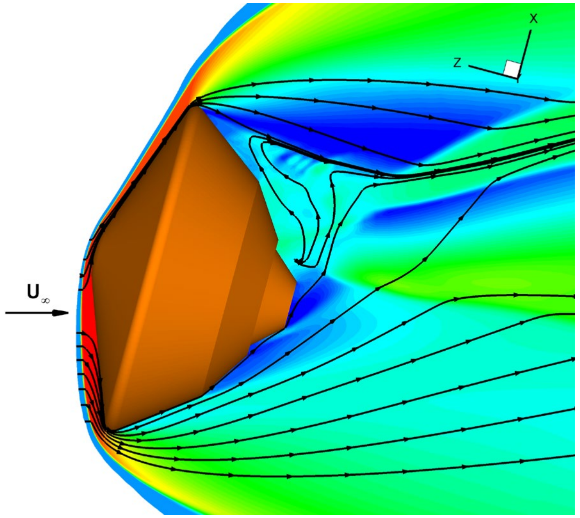
Convective Heat Flux (for example)



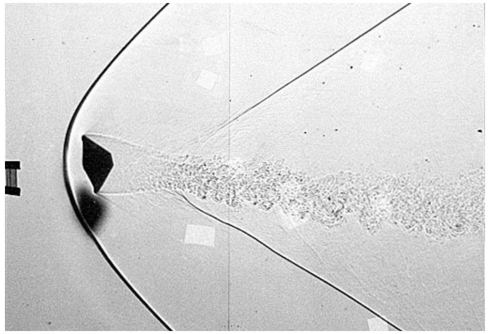
SRL Aerodynamics Overview

- The aerodynamics team is responsible for characterizing the aerodynamic properties (lift, drag, stability) of the capsule between the times of atmospheric interface and parachute deployment (plus a little longer)
  - Entry interface: ~6000 m/s
  - Parachute deployment: ~500 m/s
- The SRL capsule aerodynamic characteristics will be similar to MSL and Mars 2020 because the heatshield shapes are the same
  - The larger size, higher mass, and different aftbody shape of the SRL capsule do not have first-order effects on the aerodynamics
- To date, the Mars 2020 aerodynamics model (which was first developed for MSL) has been used for SRL EDL simulations
- The SRL aerodynamics model will be updated with a combination of computational fluid dynamics (CFD), wind tunnel testing, and ballistic range testing

CFD analysis of MSL

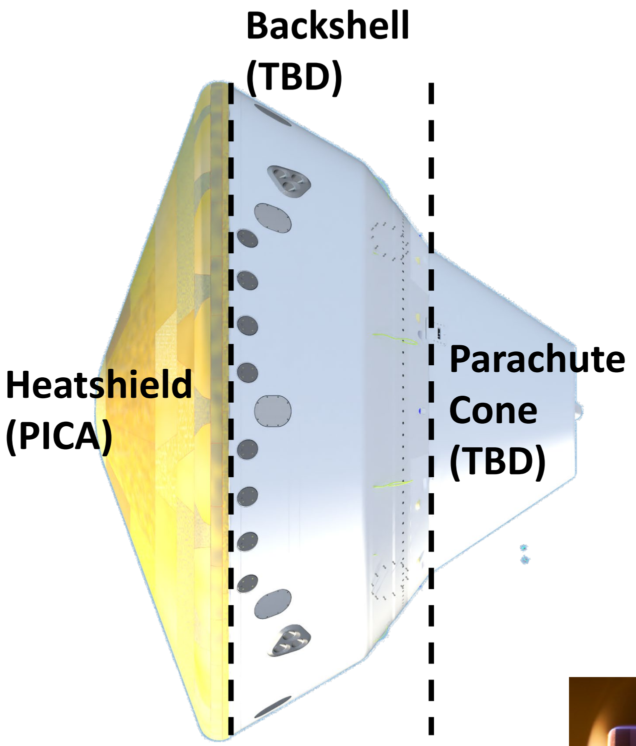


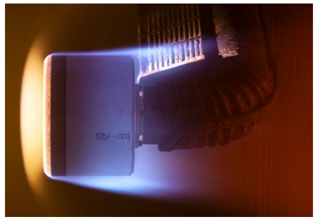
Ballistic range testing of Mars Exploration Rover geometry



SRL Aeroheating/TPS Overview

- The SRL capsule will be covered by multiple TPS materials to protect the aeroshell structure and payload from over-heating
  - For MSL and Mars 2020, the TPS materials were 0.5 to 1.25-in thick
- The SRL heatshield will use the same TPS material as MSL and Mars 2020: Phenolic Impregnated Carbon Ablator (PICA)
  - The backshell and parachute cone materials have not yet been selected
- The SRL aeroheating predictions will be based solely on CFD predictions, since test facilities cannot duplicate the Mars environment
  - The TPS materials will be tested in high-temperature arcjet facilities at NASA Ames
- The SRL aeroheating magnitudes (TPS temperatures) will be <u>higher</u> than MSL and Mars 2020 due to the <u>higher ballistic coefficient</u>





Mars 2020
PICA Arcjet Testing

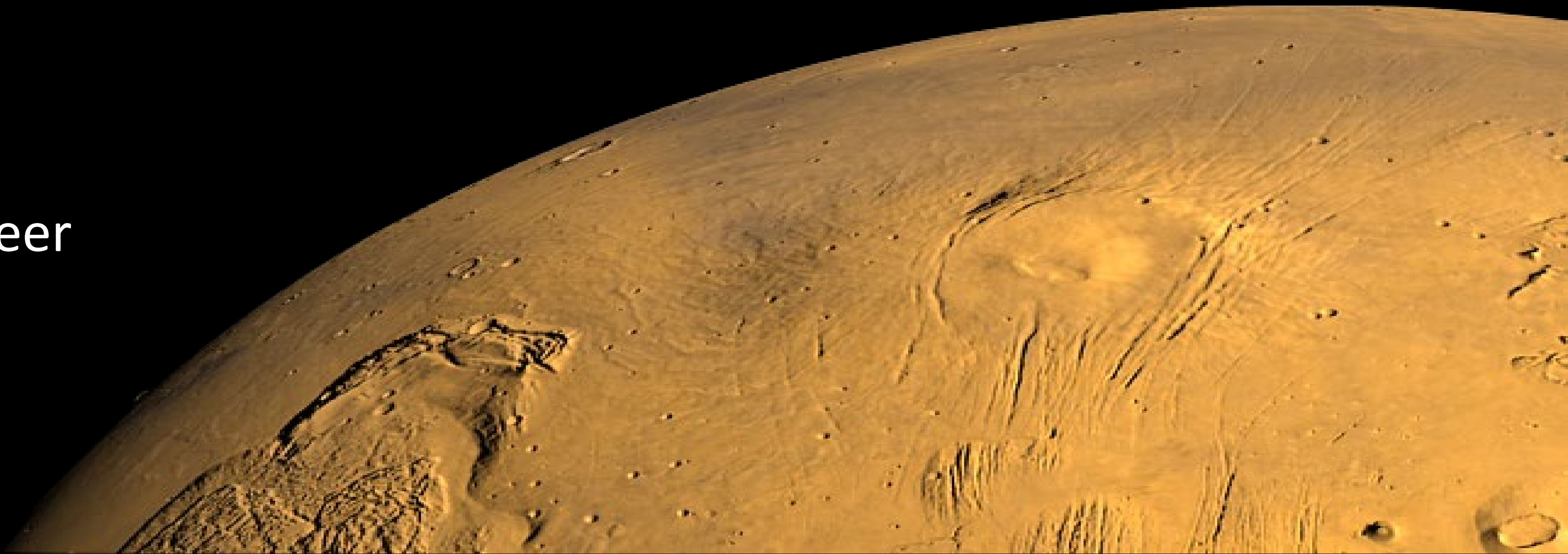
Ongoing SRL EDL Trade Studies

- Heatshield diameter, backshell geometry
  - How large can/should we make the capsule to provide the necessary performance and internal volume, that fits into the launch vehicle and still can be manufactured/tested/transported?
- Higher L/D (higher angle of attack)
  - How much more L/D can/should we use to provide the necessary performance without deviating too much from MSL and Mars 2020 and possibly requiring too much new testing?
- Parachute size
  - How much larger can/should the parachute be without deviating too much from MSL and Mars 2020 and possibly requiring too much new costly Earth high-altitude testing?
- Reaction control system (RCS) thrusters
  - Which engines should we use? How many? Where should they be located?
- Are additional flight system elements necessary?
  - Ballute, trim tab(s), inflatable aerodynamic decelerator

Earth Entry Vehicle (EEV)

Jim Corliss

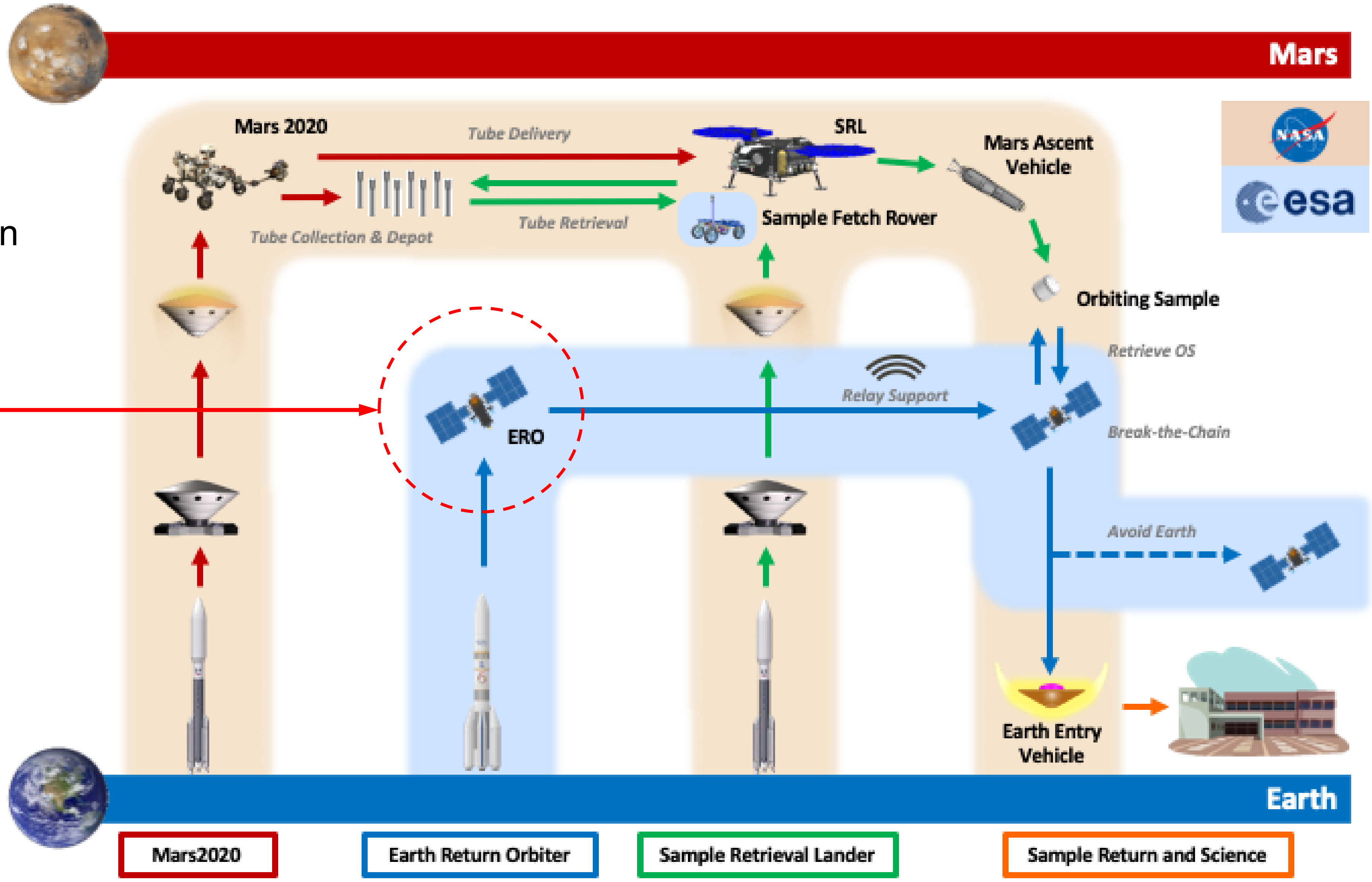
EEV Chief Engineer



MSR Campaign Overview (from AAS 20-106)

- The Earth Entry Vehicle (EEV) is an element of the Capture, Contain, and Return System (CCRS) payload launched on the ESA Earth Return Orbiter (ERO)

- The CCRS is provided to ESA by the Goddard Space Flight Center (GSFC) with components from GSFC, JPL, and ARC



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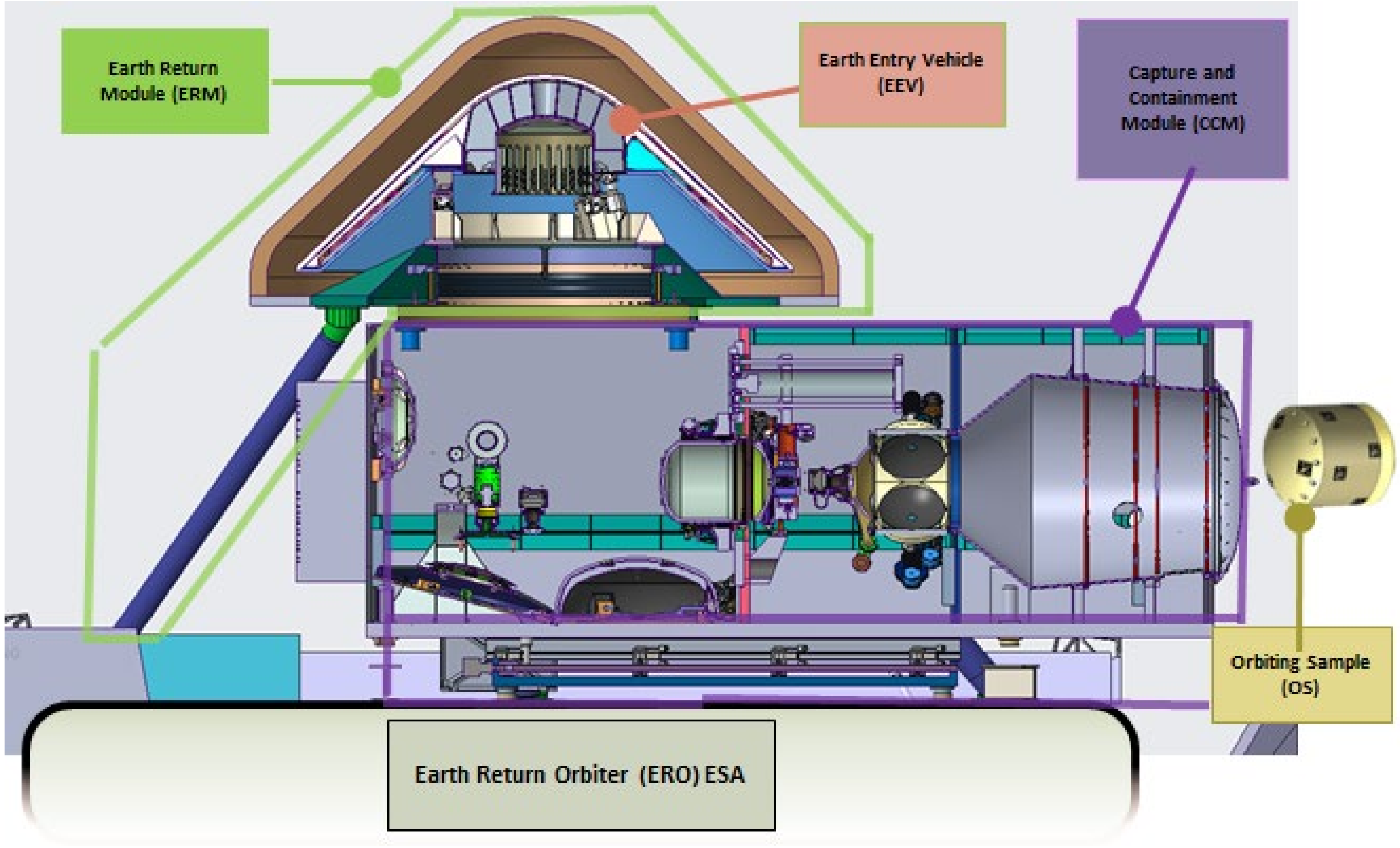
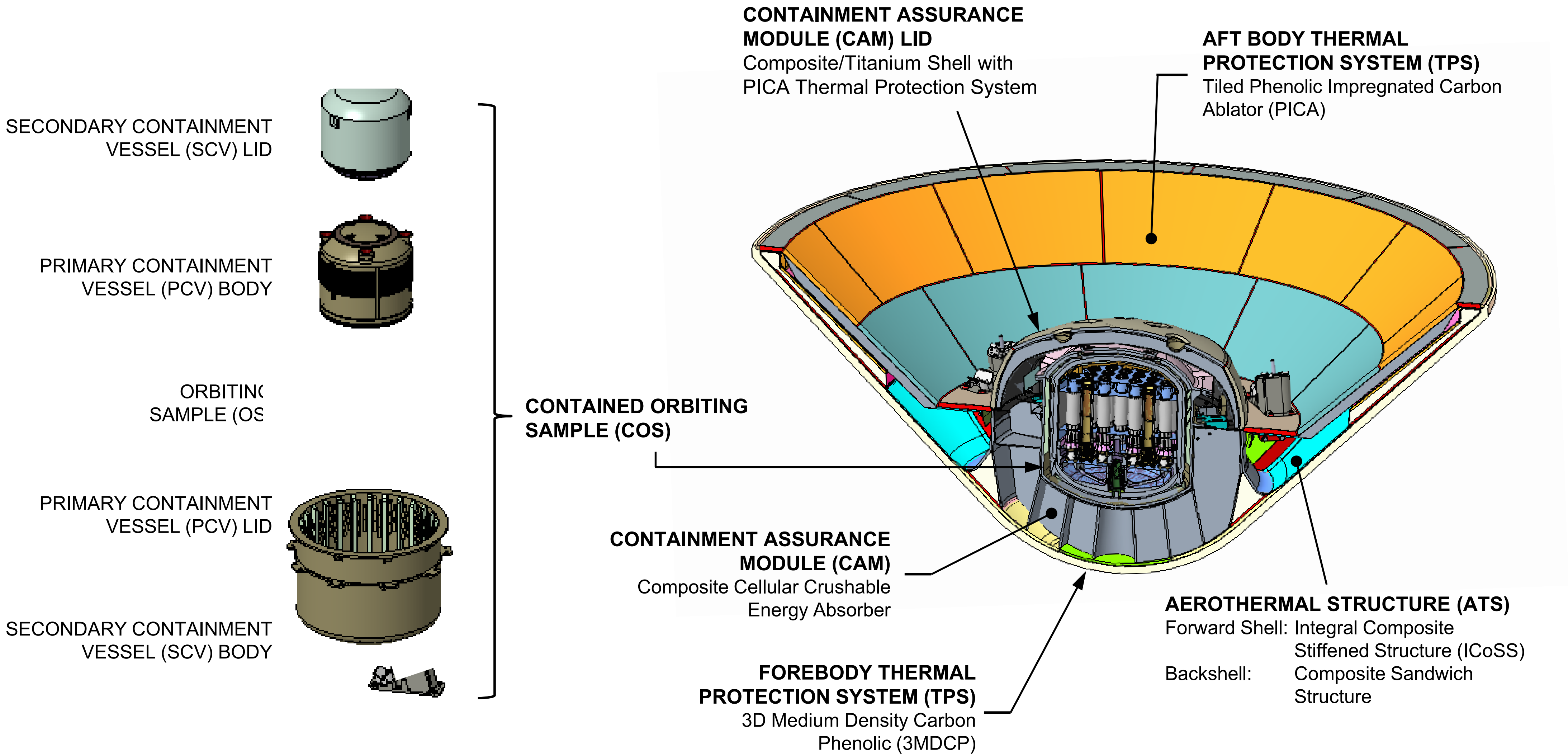
Capture, Contain, and Return System (CCRS)

- The EEV components are assembled in Mars orbit by CCRS after ERO captures the Orbiting Sample (OS) and secures it inside two layers of containment vessels

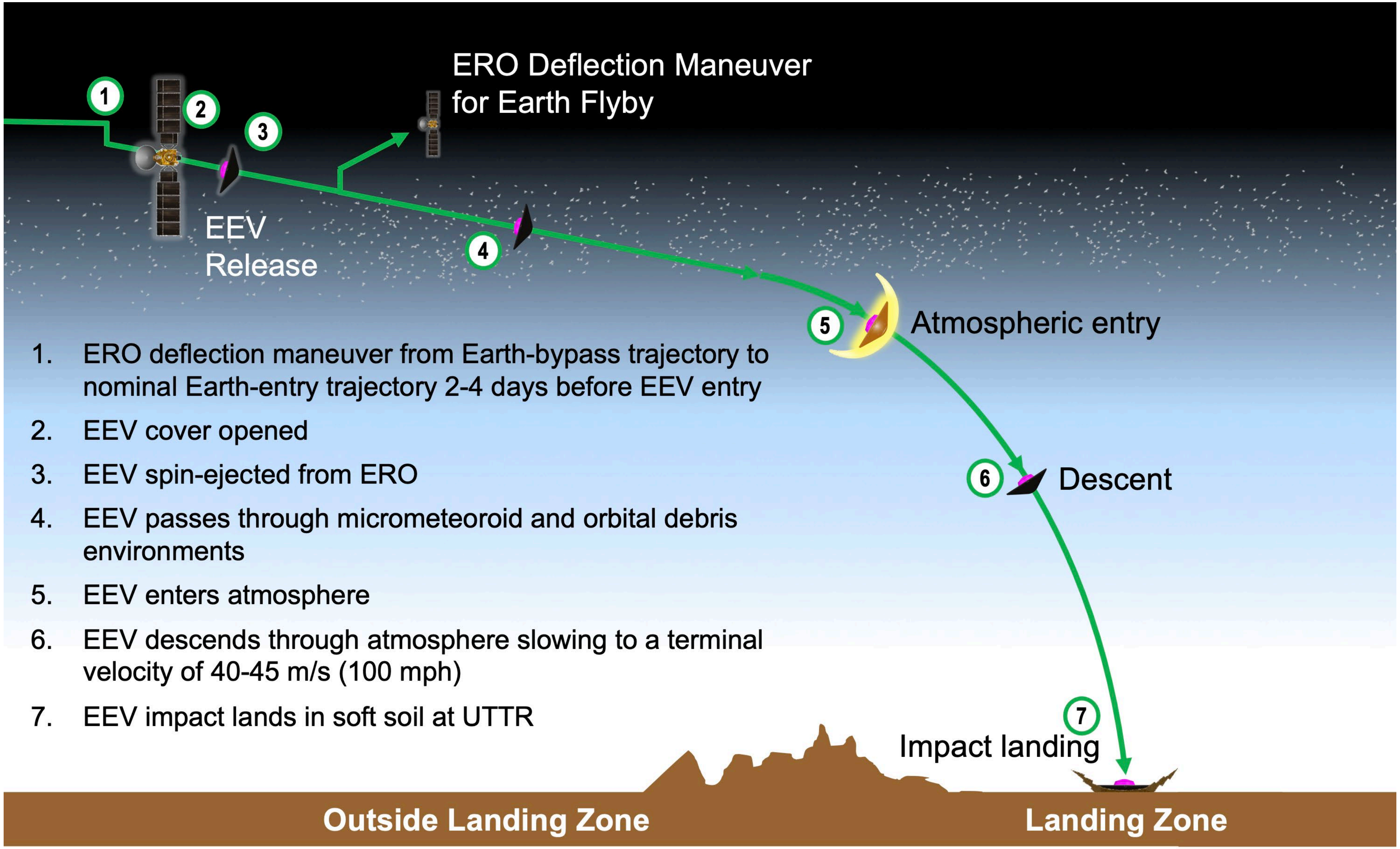
- Mars Sample Return is classified as a “Restricted Earth Return” mission that dictates rigorous protocols to assure containment of the Mars samples and Earth planetary protection



Current Earth Entry Vehicle (EEV) Configuration



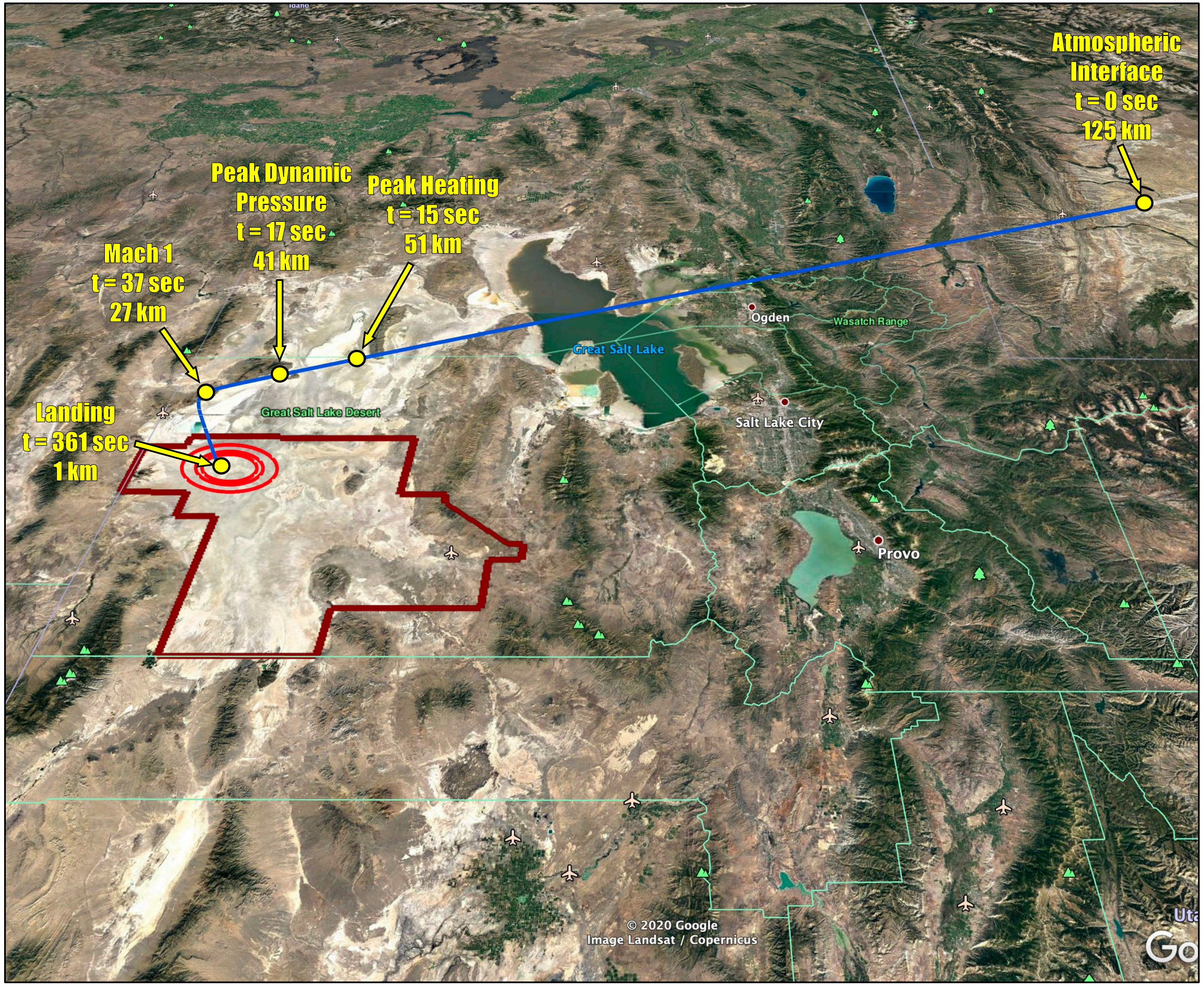
EEV Approach, Entry, Descent and Landing (AEDL) Conops



EEV EDL Parameters and Environments Overview

Key Differences Between MSR and Previous Sample Return Mission Capsules and EDL

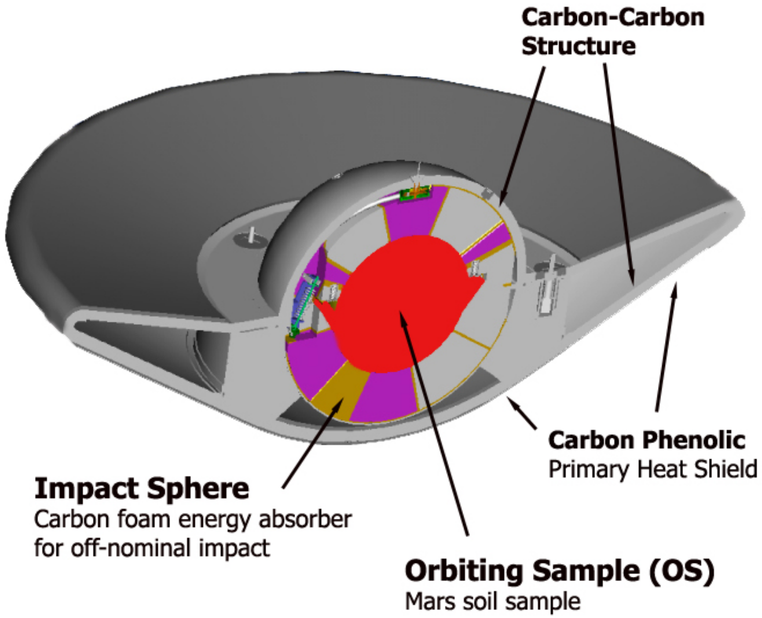
Capsule / EDL Parameter	MSR	Stardust	Genesis	OSIRIS REx
Entry Mass (kg)	< 92.5	46	225	53
Capsule Base Diameter (m)	1.25	0.81	1.52	0.81
Sphere-Cone Angle (deg)	45	60	60	60
Entry Type	Ballistic	Ballistic	Ballistic	Ballistic
Inertial Entry Velocity (km/s)	12.0	12.9	11.0	12.7
Entry Flight Path Angle (deg)	-25	-8.2	-8.3	-8.2
Entry Acceleration (G)	170	40	30	40
Parachute System	None	Drogue + Main	Drogue + Main	Drogue + Main
Time from Release to Entry	2 to 4 days	4 hours	4 hours	4 hours
Spin Rate (RPM)	5	14	16	15



EEV History

The original Earth Entry Vehicle (EEV) concept was developed at the NASA Langley Research Center in 1998 as an enabling technology for the 03/05 Mars Sample Return Mission (MSR).

- *Back planetary protection requirements demanded a sample return capsule with unprecedented reliability*

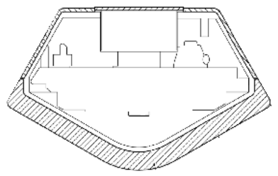


Drop Testing of the First EEV Prototype at the Utah Test & Training Range (UTTR) in 2000

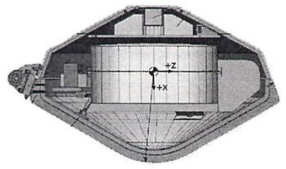
EEV History

EEV Outer Mold Lines - *Key Criteria*

1. **Accommodate the Mars sample container and crushable energy absorber**
2. **Aerodynamically stable (entry to ground)**
3. **High aerodynamic drag (reduce landing velocity)**

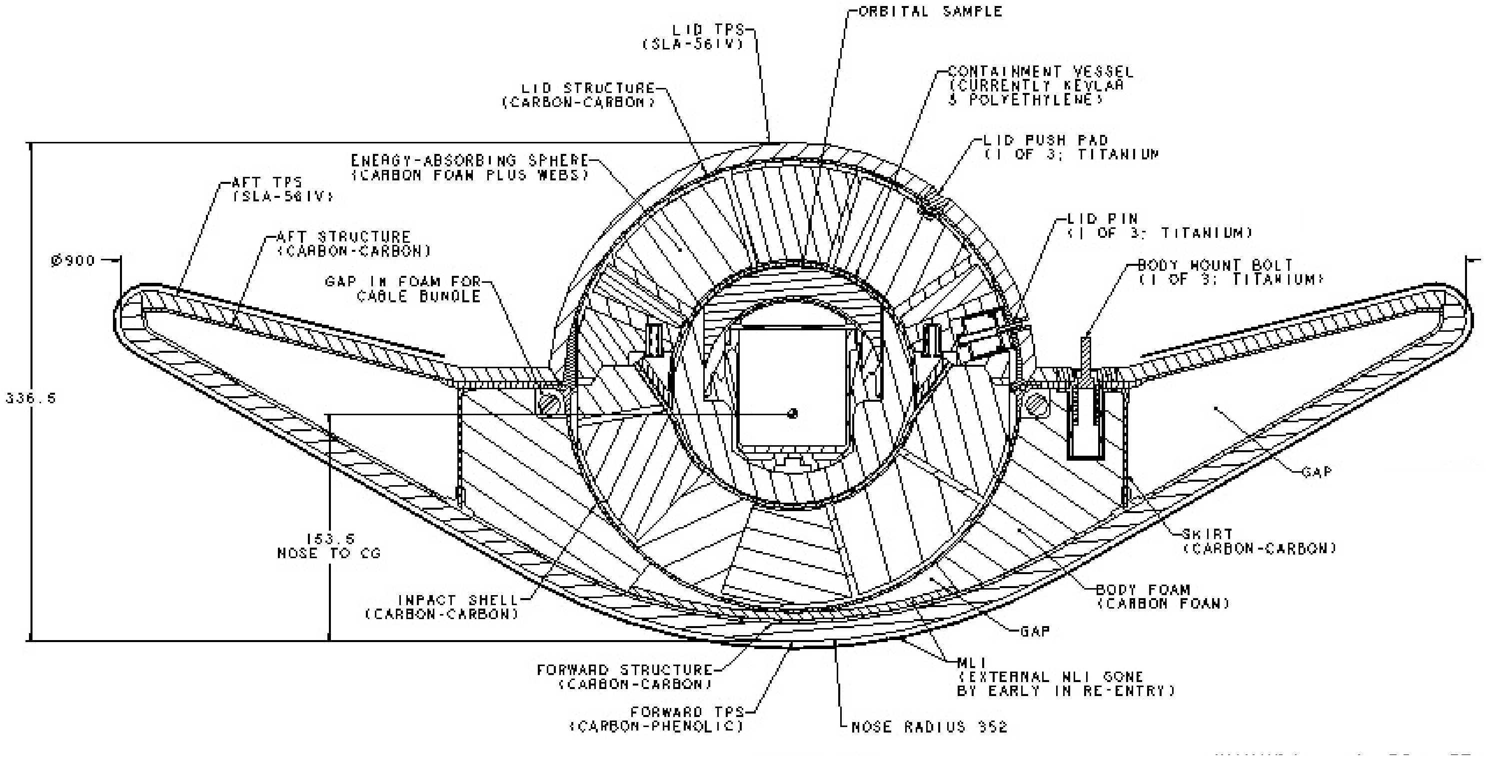


Stardust Sample Return Capsule
Launched Feb. 7, 1999
Landed UTTR Jan. 15, 2006



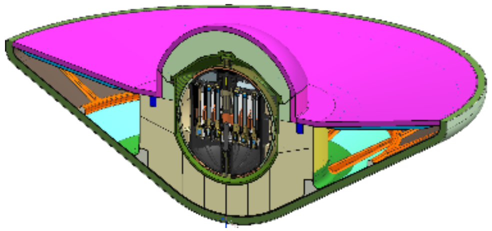
Genesis Sample Return Capsule
Launched Aug. 8, 2001
Landed UTTR Sep. 8, 2004

EEV Design Concept for 2003/05 MSR Mission

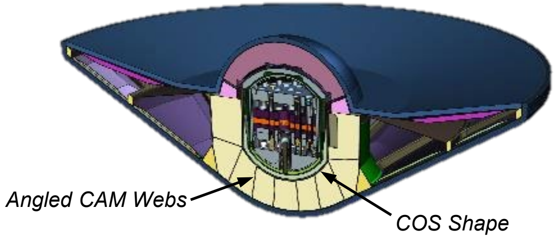


EEV Design History for 2026 / 2028 Mission

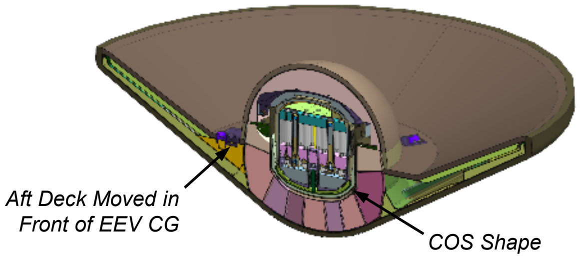
DAC-1 Closure
October 17/18, 2018
Integrated Concepts TIM



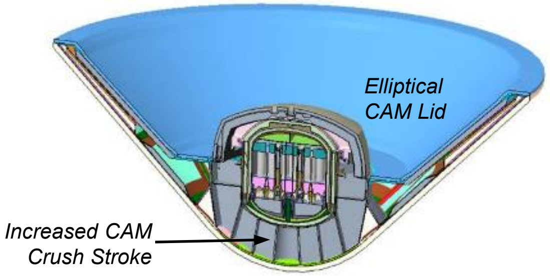
DAC-2A Closure
May 13, 2019
EEV Peer Review



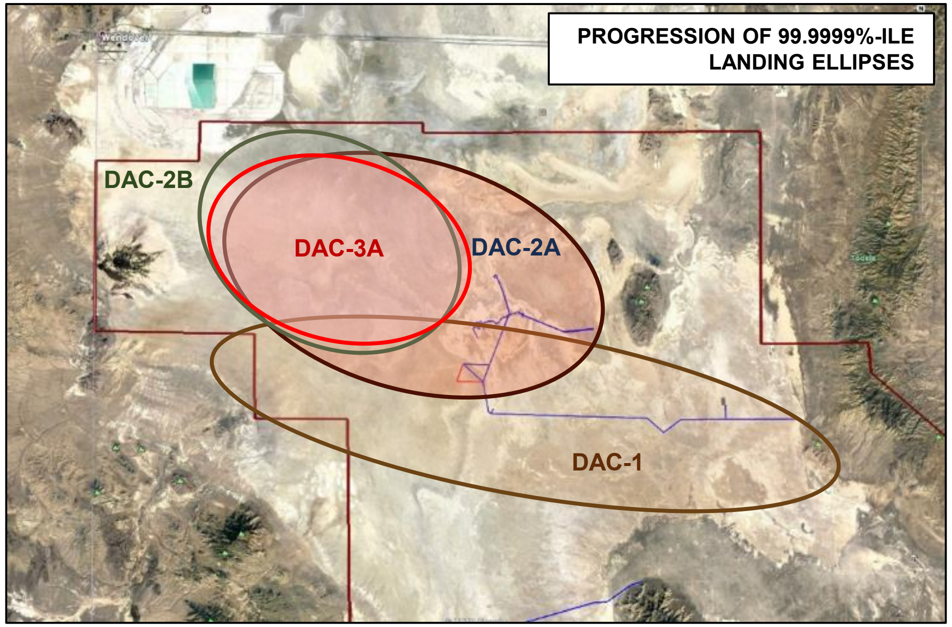
DAC-2B Closure
January 22, 2020
CRASPR



DAC-3A Closure
September 23, 2020
DAC-3A Closure TIM



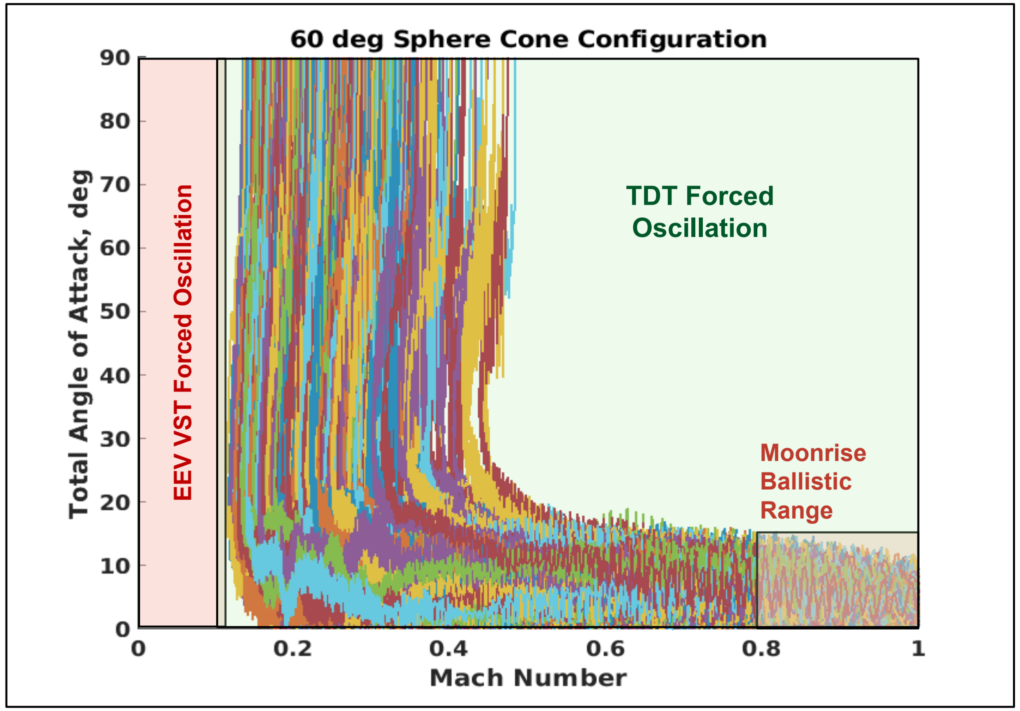
	EEV Design Progression			
Design Parameter	**DAC-1 Closure**	**DAC-2A Closure**	**DAC-2B Closure**	**DAC-3A Closure**
Inertial Entry Velocity (km/s)	12.0	12.0	12.0	12.0
Entry Direction	Retrograde	Retrograde	Retrograde	Retrograde
Entry Flight Path Angle (Deg)	-12	-18	-25	-25
99.9999%-ile Ellipse Major Axis (km)	80.9	43.1	29.4	28.0
Base Diameter (m)	1.30	1.30	1.30	1.30
Sphere-Cone Half Angle (Deg)	60	60	60	45
Forebody TPS	PICA	PICA	3MDCP	3MDCP
Aft Body TPS	PICA	PICA	PICA	PICA
Forward Shell Structure	T300 ICoSS	T300 ICoSS	T300 ICoSS	T300 ICoSS
COS Mass (kg NTE)	33.0	23.0	26.2	26.2
EEV MEV with NTE COS (kg)	**70.9**	**85.0**	**92.1**	**89.9**



Aerodynamic Stability

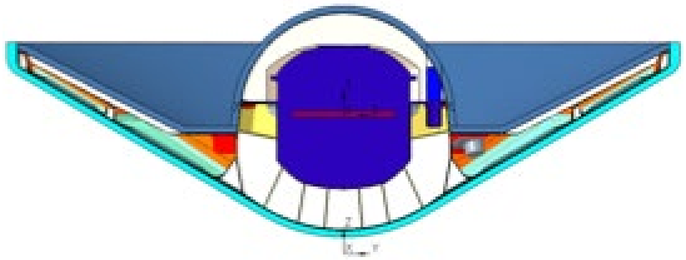
Early Aerodynamic Tests are Focusing on Filling Data Gaps for Subsonic/Transonic Sphere Cone Dynamics

- Vertical Spin Tunnel free-flight
- Vertical Spin Tunnel forced oscillation
- Transonic Dynamics Tunnel forced oscillation
- Aberdeen Proving Grounds ballistic range

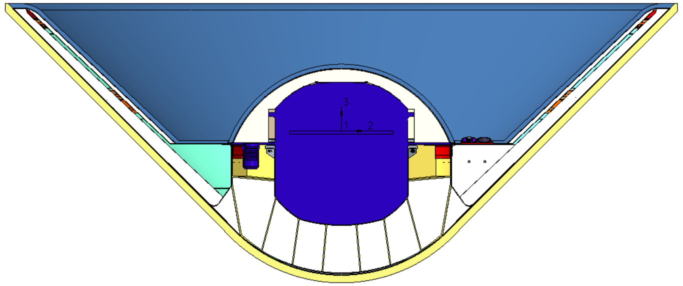


Tumbling cases from 60-deg EES Monte Carlo - Ben Tackett, NASA LaRC

60-Degree Sphere Cone EEV Concept



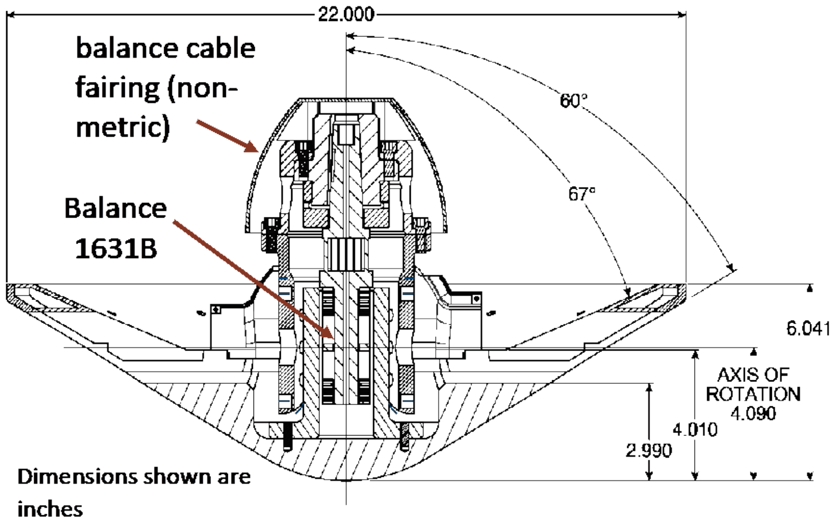
45-Degree Sphere Cone EEV Concept



TDT Testing Configuration

Test Engineers: Bruce Owens, Rose Weinstein

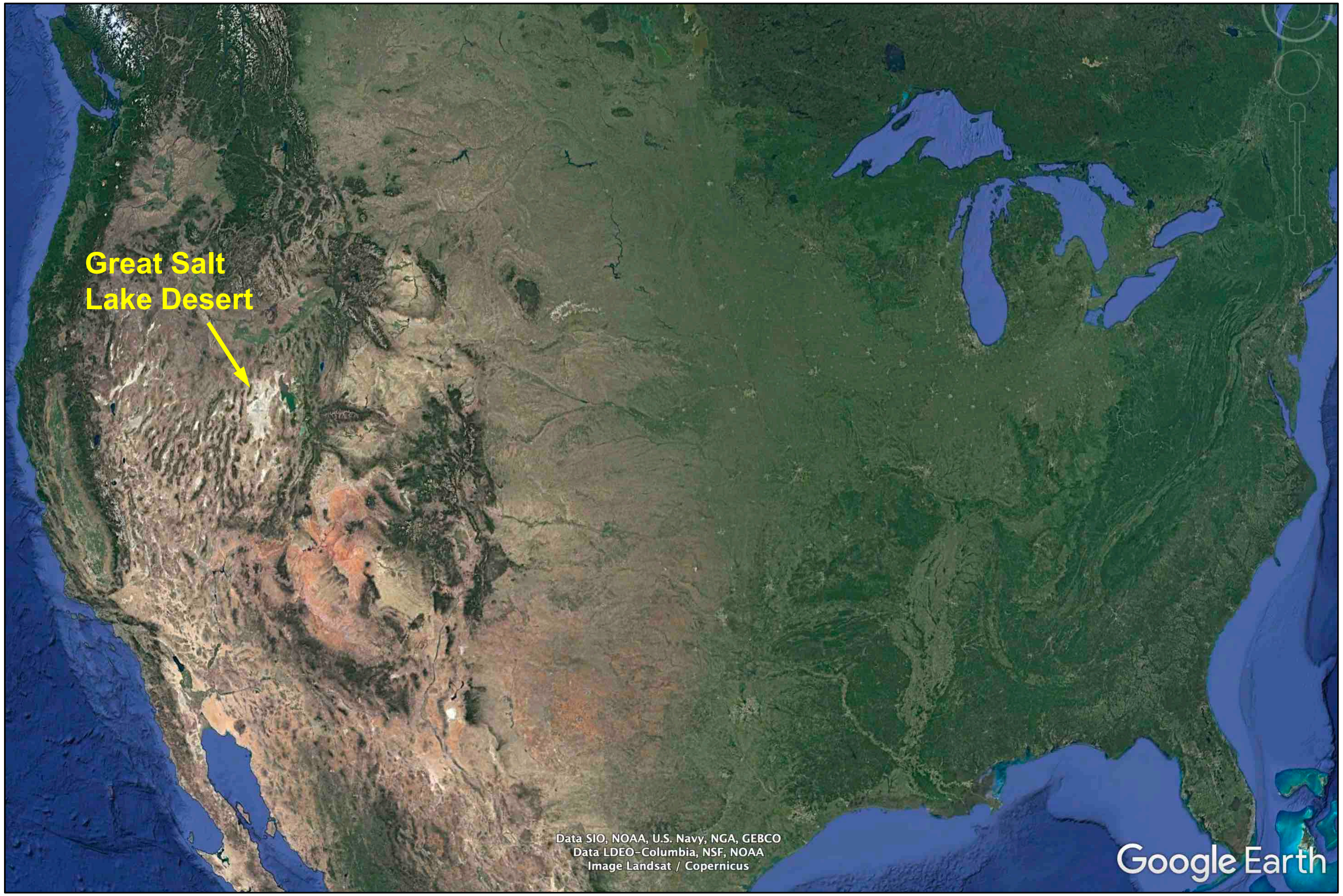
- Model Scale: 43%
- Ref Length = 0.559 m (22 in.)
- Ref Area = 0.245 m^2 (380.1 in^2)
- Model Oscillation Center:
  - Xcg/D, measured from nose
  - 45 deg: Xcg/D = 0.252
  - 52.5 deg: Xcg/D = 0.219
  - 60 deg: Xcg/D = 0.186



Boeing CST-100 (Abort Configuration) - December 2014
Prior test in TDT that used Transverse Sting and OTT

EEV Landing Conditions

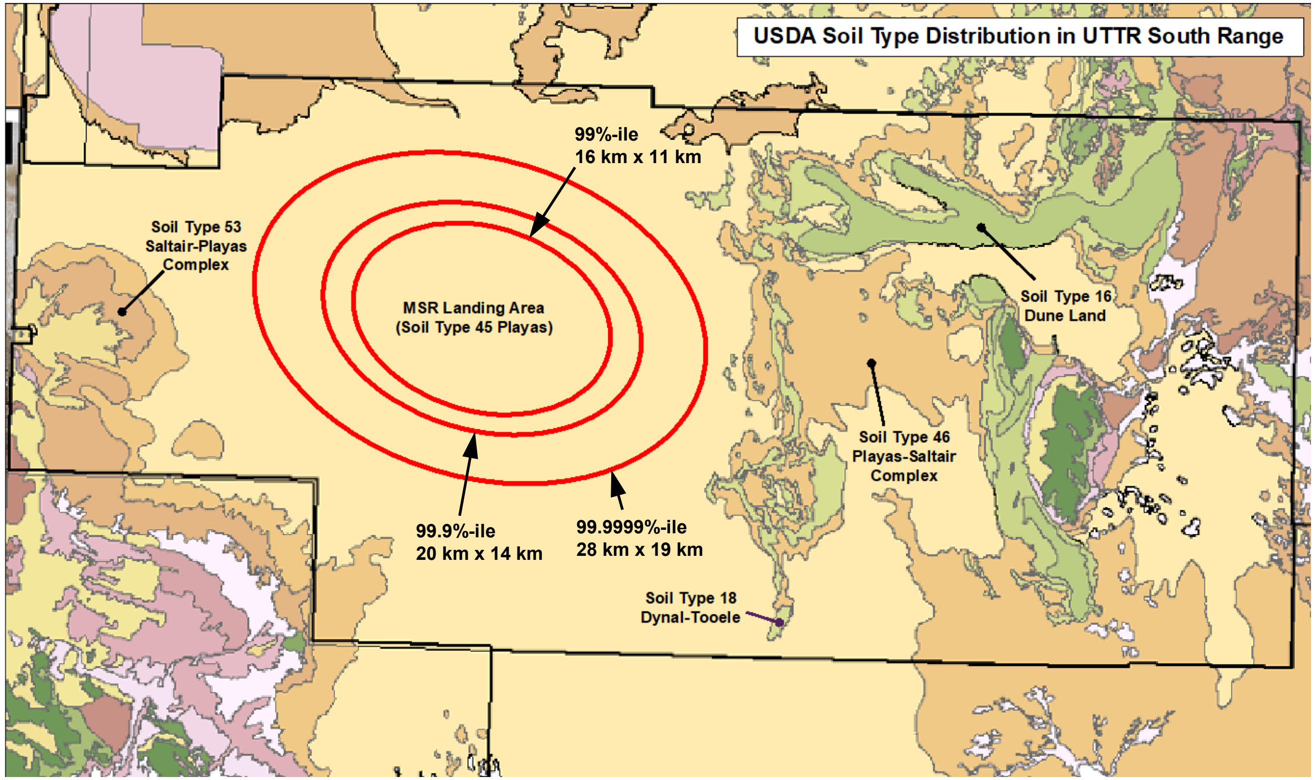
- One of the unique aspects of Mars Sample Return EEV is the high velocity landing without a parachute
- The Utah Test and Training Range (UTTR) is ideal for the EEV landing:
  - Largest restricted airspace in the contiguous United State
  - 6,930 km^2 controlled ground space
  - The dry lakebed (playa) soil of the Great Salt Lake Desert provides a soft surface that absorbs the energy of the EEV impact



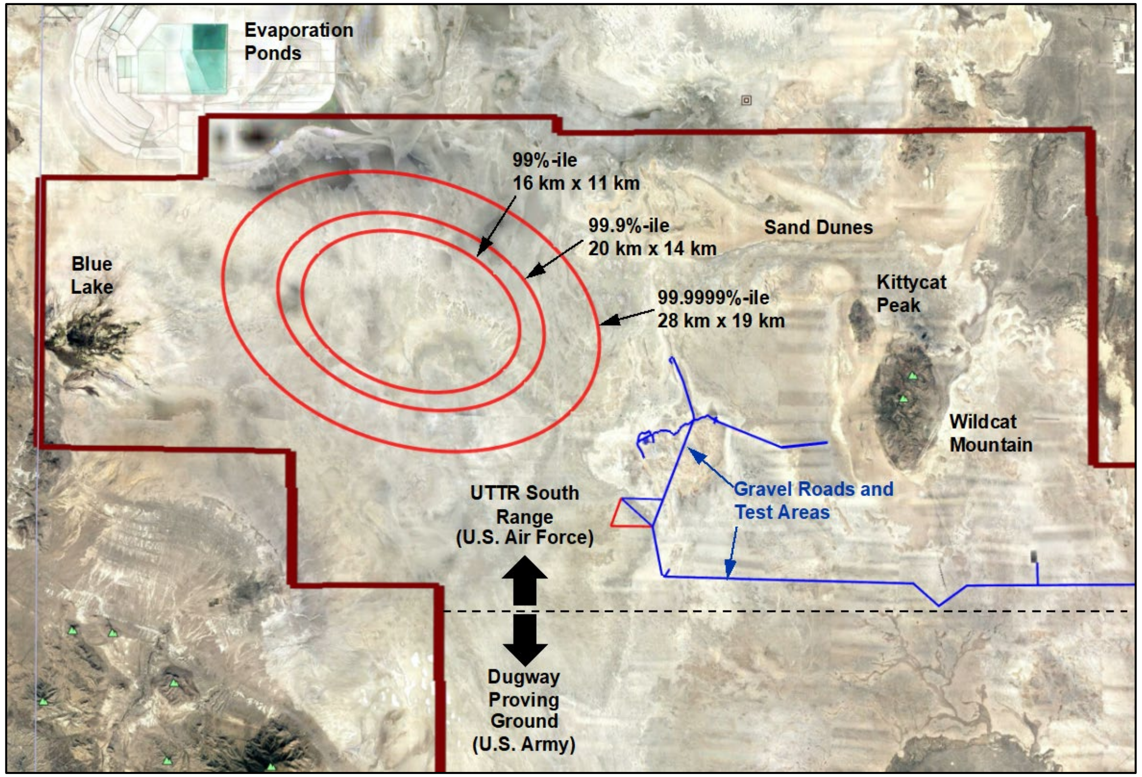
EEV Landing Conditions

Baseline Mission Architecture and EDL Design Produces Landing Ellipses Favorable for Nominal (Soil) and Off-Nominal (Hazardous) Landing Scenarios

Landing Ellipses are Fully within Soft Playa UTTR Soil to Reduce Landing Loads and Simplify Model Validation and System Verification



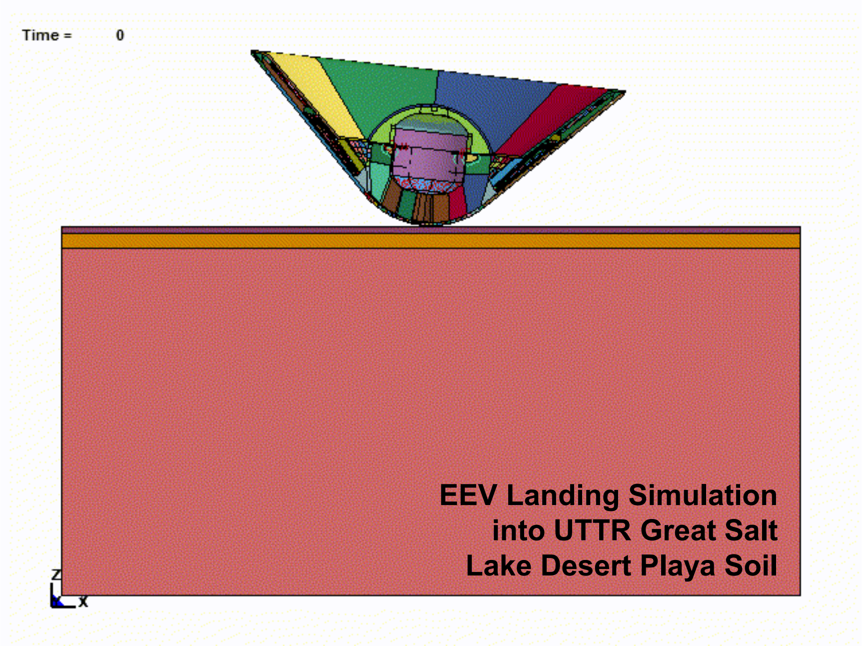
Landing Ellipses are Away from Roads and Test Areas to Reduce Hazards and Simplify Containment Assurance Verification



EEV Landing Conditions

Nominal LS-DYNA™ Soil Landing Simulations

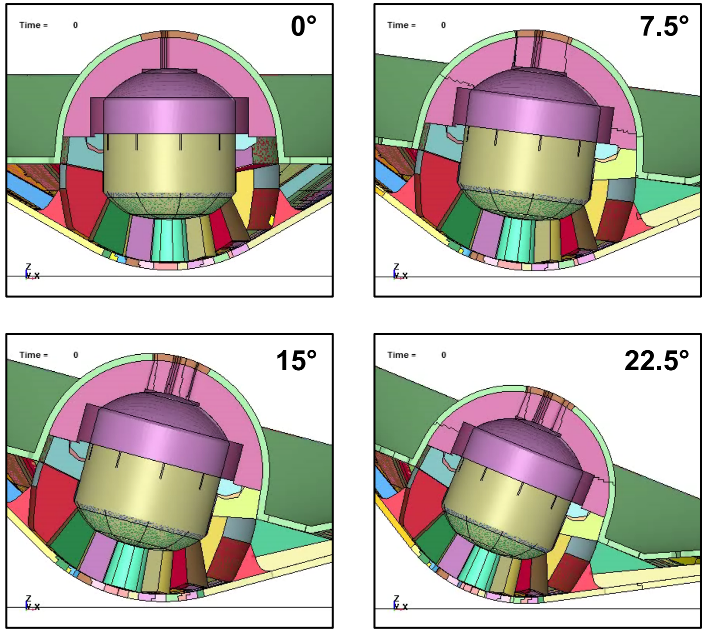
Credit: Greg Vassilakos, Langley Research Center



For nominal landings the soil absorbs the EEV kinetic energy and the impacts loads are attenuated to <1,100 g at the sample container to maintain science integrity.

Off-Nominal LS-DYNA™ Hard Surface Landing Simulations

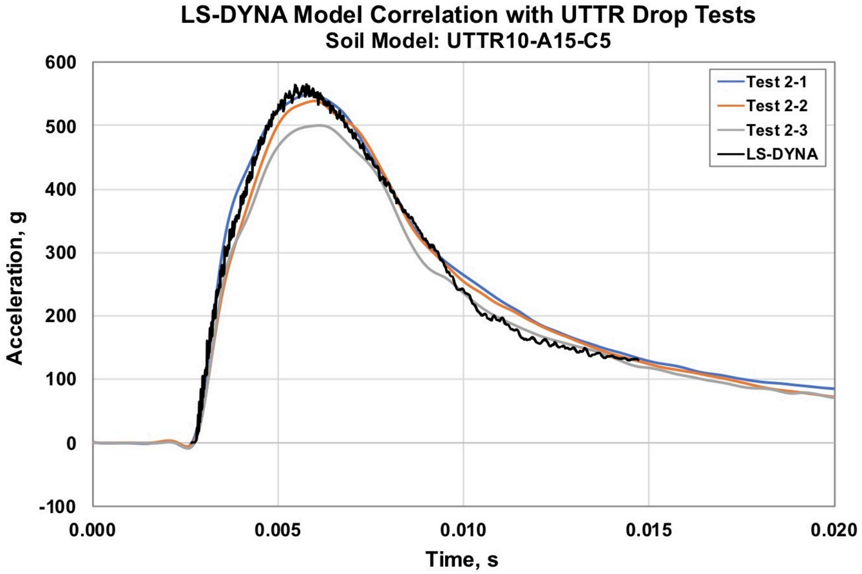
Credit: Aaron Siddens, Jet Propulsion Laboratory



For off-nominal landings onto a hard surface the EEV energy absorber limits loads to <3,000 g at the sample container to maintain back planetary protection.

Nominal Soil Landing Model Validation

- **In-Situ drop tests at UTTR are necessary to validate the LS-DYNA models and develop confidence in the EEV landing predictions**

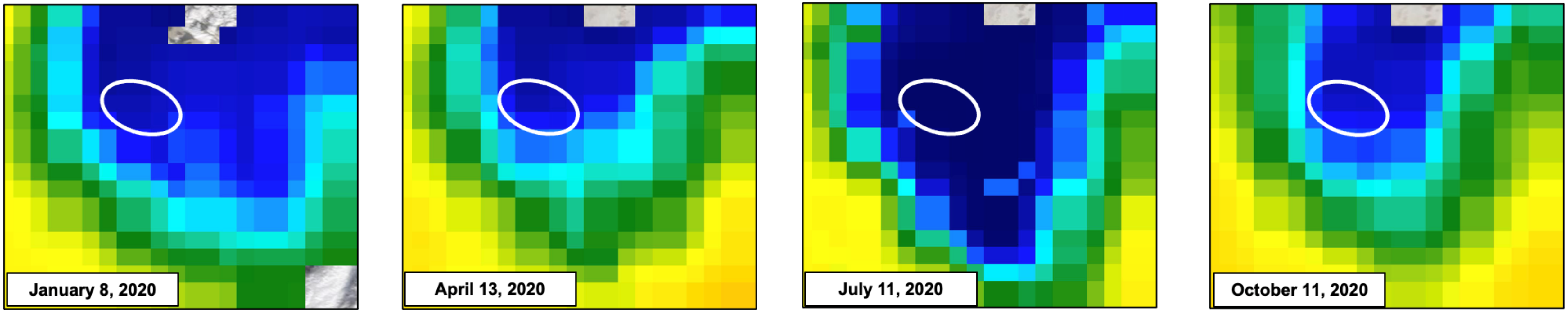


Landing Site Characterization Work

Soil Moisture Mapping - Bradley Gay, George Mason University

- Landing impact loads on the sample tubes need to be kept below 1,300 G to maintain the tube seal
- EEV impact acceleration is sensitive to the soil moisture content:
  - **Drier Soil = Stronger Soil**
  - **Stronger Soil = Higher Impact Acceleration**
- The objective of the UTTR soil moisture mapping activity is to develop temporal and spatial distributions of soil moisture content in the EEV landing area using data from NASA's Soil Moisture Active Passive (SMAP) observatory

SMAP 9 km Resolution Soil Moisture Data at UTTR
Top 5 cm of Soil
Images from NASA EOSDIS Worldview Visualization



Landing Site Characterization Work

Hazard Mapping - Sierra Luoma, Montana Tech

- To meet back planetary protection requirements, we need to ***quantify the probability*** of the EEV encountering a hazard when it lands at UTTR

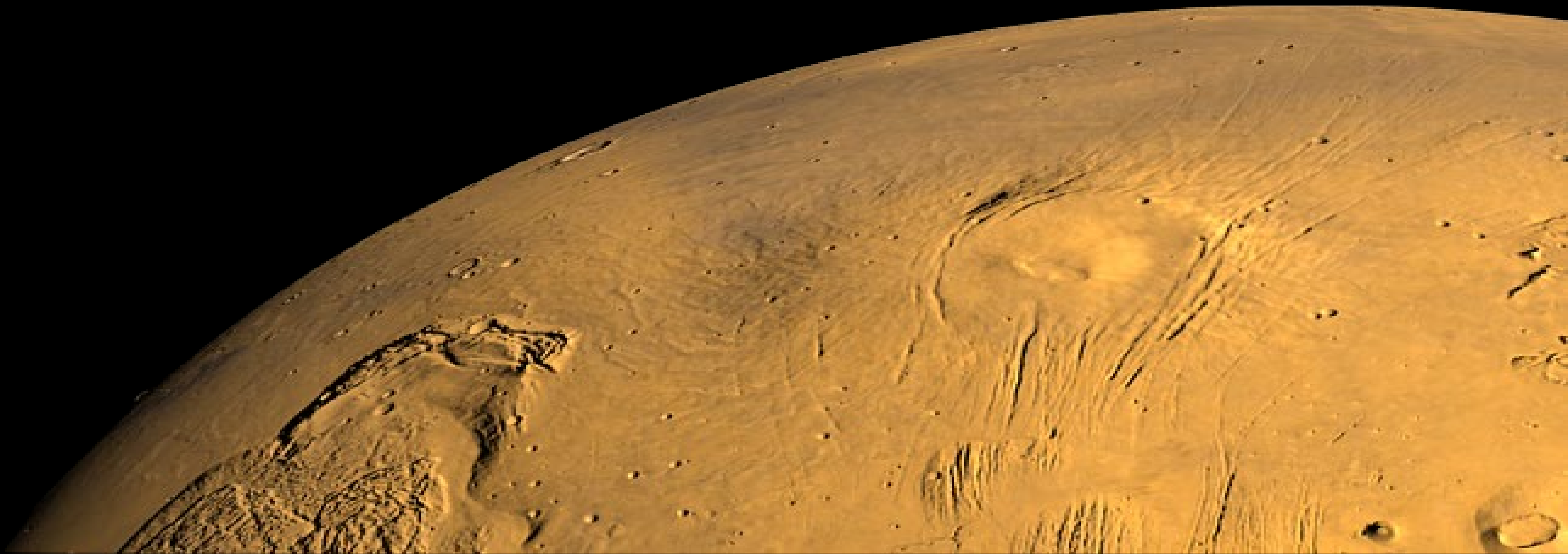
- The objective of the UTTR hazard mapping activity is to develop a database of geolocated hazards that are combined with the POST2 landing footprints to determine the EEV off-nominal landing probability

Summary

- Mars Sample Return SRL and EEV have introduced new challenges for Mars and Earth EDL
  - SRL: Size and mass of the SRL entry system potentially much greater than previous Mars missions
    - Larger parachutes and/or newer drag system technologies
    - Less EDL altitude and timeline margin
  - EEV: Chuteless EDL with stringent requirements on aerodynamic stability, hard landing impact loads, and sample containment / planetary protection
    - 45-degree sphere conge geometry instead of traditional 60-degree shape from previous sample return missions
    - New testing and characterization of blunt body subsonic / transonic aerodynamics
    - Thorough characterization of landing site soil and hazards

- Questions?

Backup



Mars Sample Return Campaign Objectives (from AAS 20-106)

- Acquire and return to Earth a scientifically-selected set of Mars samples for investigation in Earth laboratories.
- Select samples based on their geologic diversity, astrobiological relevance, and geochronologic significance.
- Establish the field context for each sample using in-situ observations.
- Ensure the scientific integrity of the returned samples through contamination control (including round-trip Earth contamination and sample-to-sample cross-contamination) and control of environments experienced by the samples after acquisition.
- Ensure compliance with planetary protection requirements associated with the return of Mars samples to Earth's biosphere.
- Achieve a set of sample-related scientific objectives including: life, geologic environments, geochronology, volatiles, planetary-scale geology, environmental hazards, and In-Situ Resource Utilization (ISRU)

M. Ivanov and S. Sell, "Challenges of Mars Sample Return Entry, Descent, and Landing," AAS 20-106, Annual AAS Guidance, Navigation and Control Conference, January 2020