Detailed Design of an Earth Entry Vehicle for Comet Surface Sample Return

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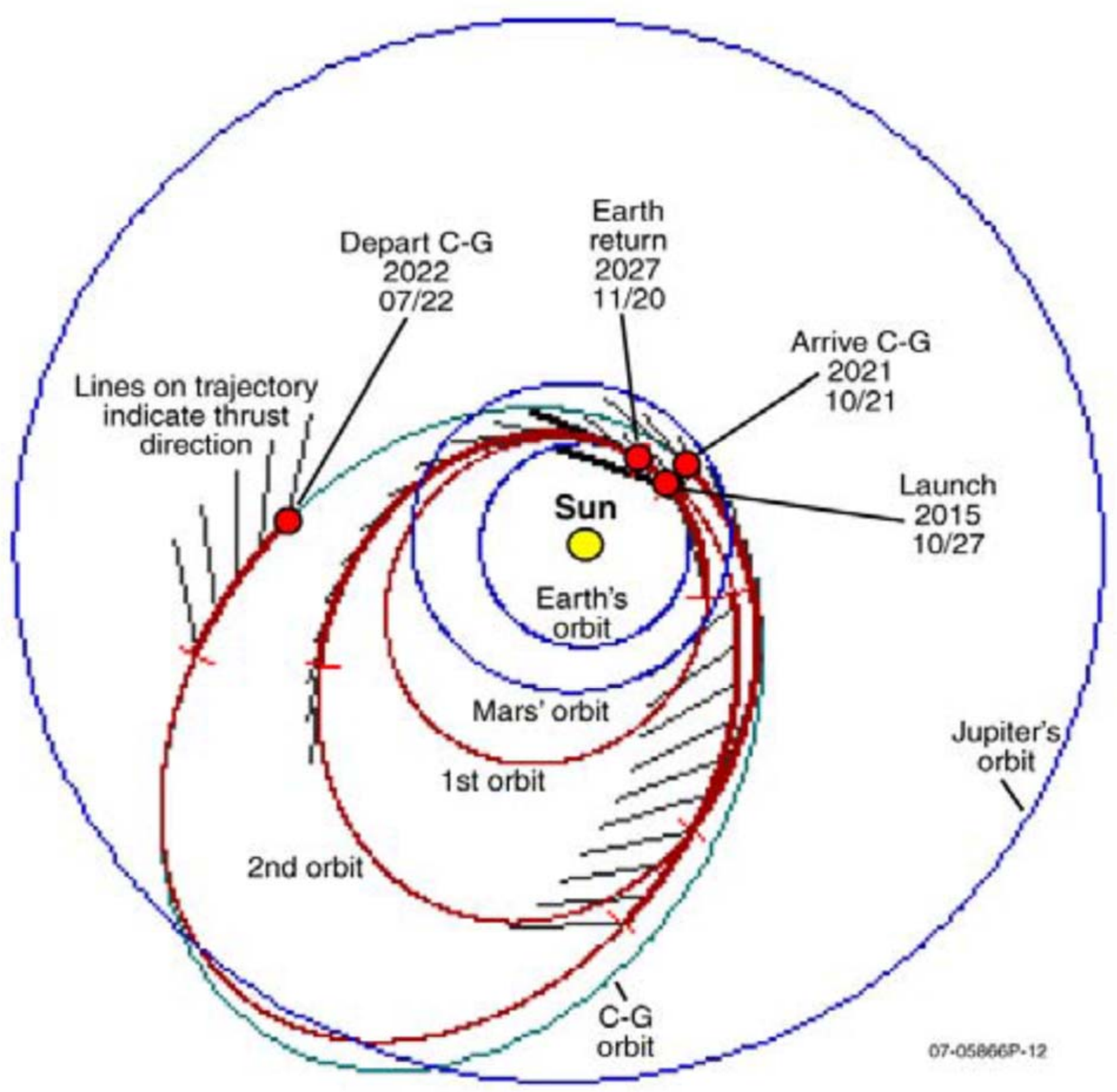
Comet Surface Sample Return Mission

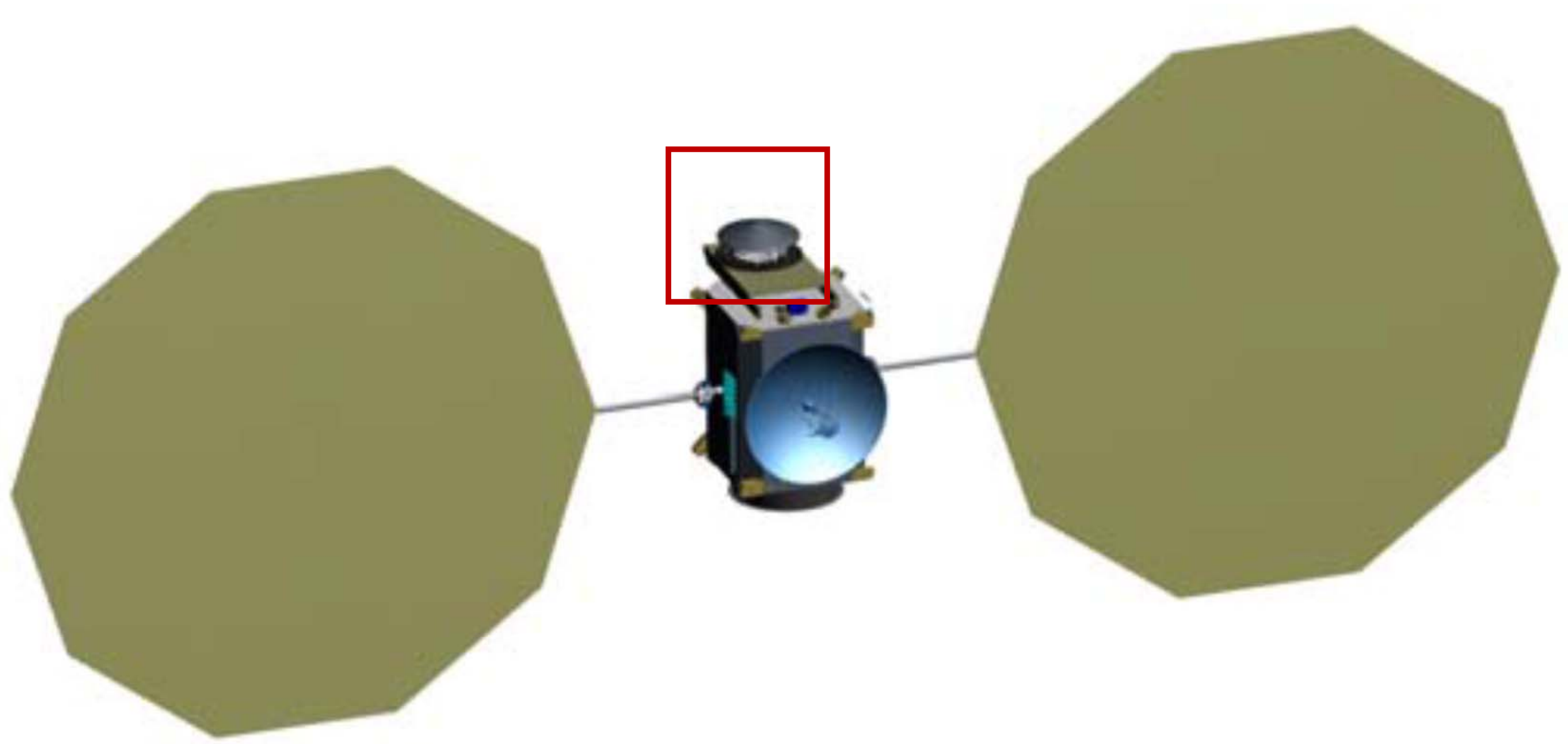
- The 2013 Decadal Survey for New Frontiers cites Comet Surface Sample Return (CSSR) as a high-value science mission.[1]
- Goals of the CSSR mission are to:
  - Understand the contribution of comets to Earth's volatile inventory,
  - Advance fundamental understanding of the origin of the solar system
- The CSSR mission has a fundamental requirement to acquire and return to Earth for laboratory analysis a macroscopic comet nucleus surface sample.
- An Earth Entry Vehicle (EEV) will protect the payload (sample) from extreme conditions of atmospheric entry, descent, and landing.

CSSR Mission & Entry Vehicle

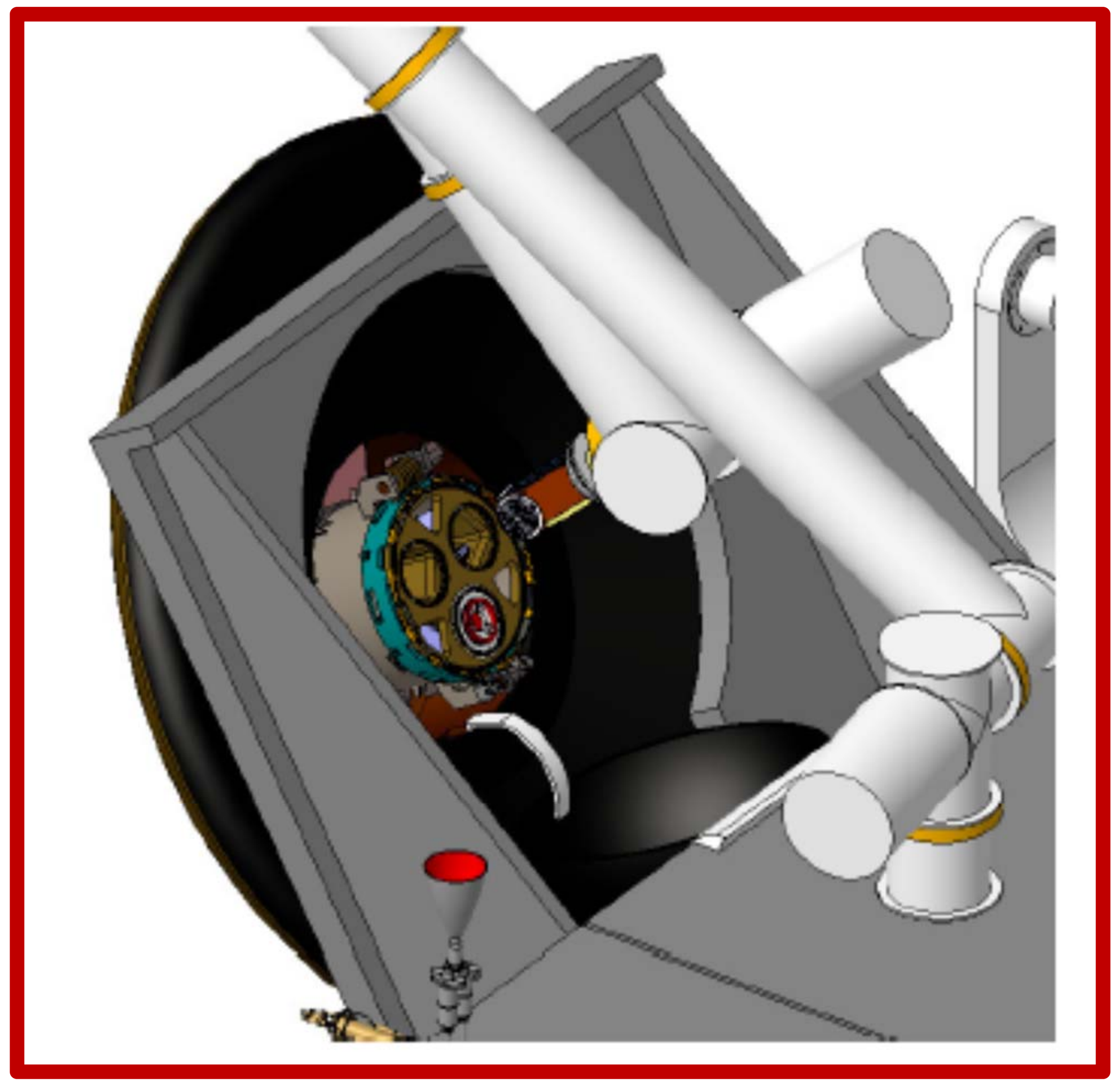
- 2007-2008 APL Concept study considered chemical and solar electric propulsion (SEP) for the spacecraft.[2]
- Current design has Earth return with an entry velocity higher than Stardust (12.6 km/s),
  - 14.2 km/s inertial, 13.86 km/s atmospheric relative.
- Adams et al. described spacecraft bus and sample operations,[3]
  - 1.14 m diameter 60º half-angle forebody,
  - Embedded sample storage system, hermetically sealed with up to three samples,
  - Robotic arm to insert samples into canister through backshell lid.



CSSR visit to Jupiter-family comet[2]



SEP Spacecraft with EEV highlighted

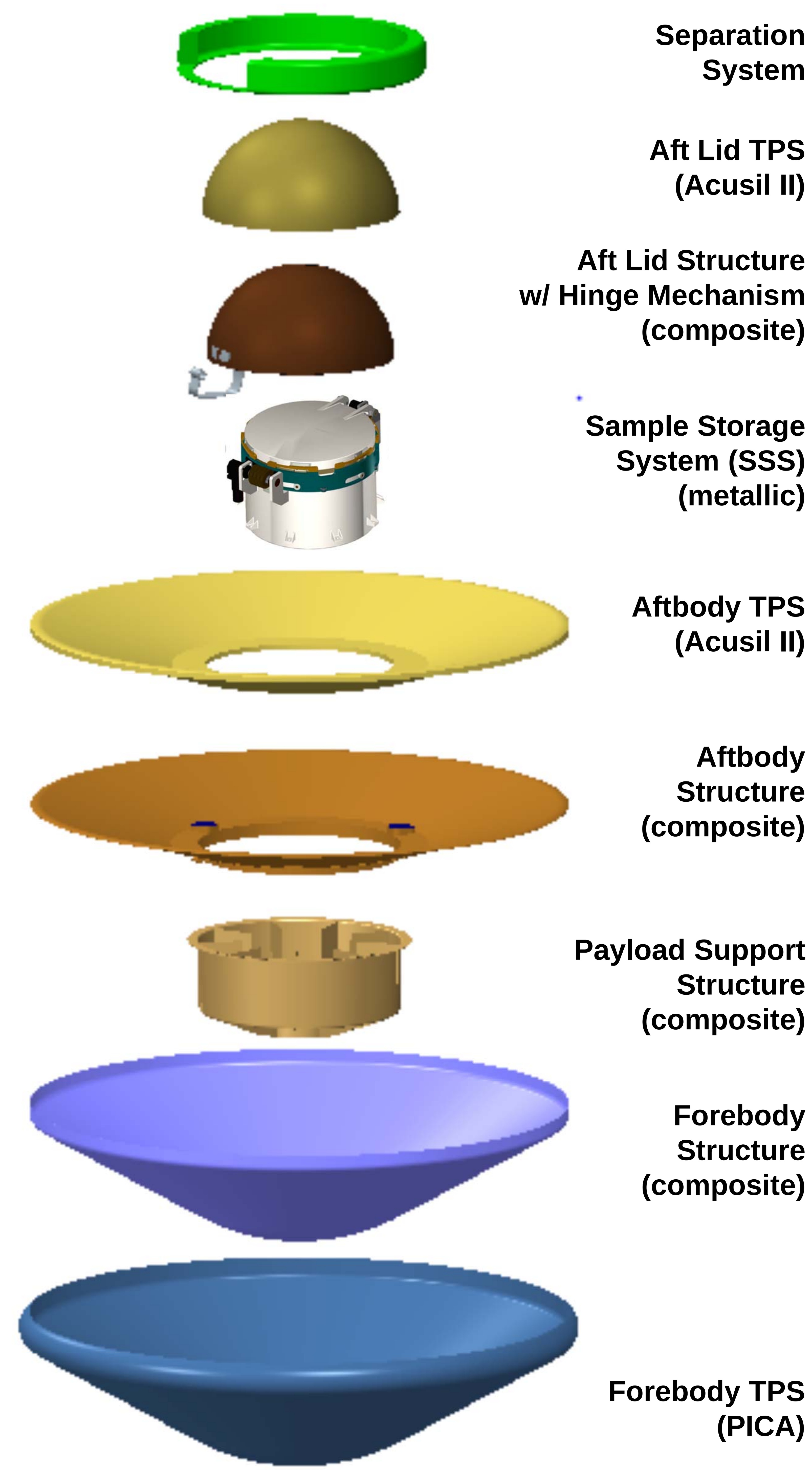


Detail of EEV during payload insertion

CSSR Earth Entry Vehicle

- The CSSR EEV protects the cometary payload during atmospheric entry,
  - The EEV is a chuteless design[4] that is stable at all Mach numbers,
  - Samples are stored in a metal sample storage system (SSS) within the EEV,
  - Rigid structure protects payload canisters during landing impact event.[5,6,7]
- Main EEV main components are:
  - Composite structure aeroshell and payload support,
  - Thermal protection system (TPS) on heatshield and aftbody,
  - Mechanisms: motors and hinges for lid actuation and separation system attachments,
  - EDL instrumentation.

Breakdown of EEV Components



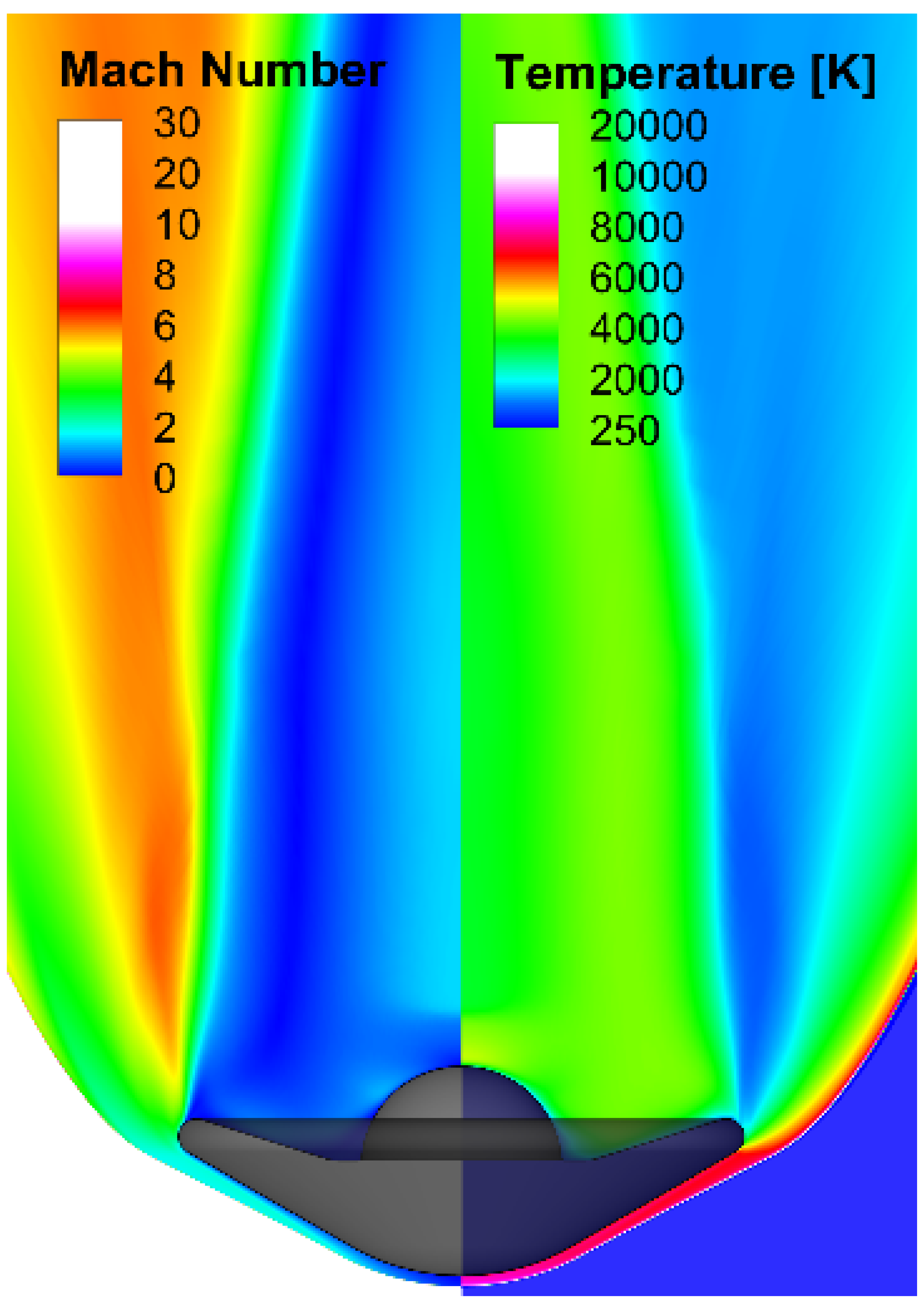
EEV with aft lid open

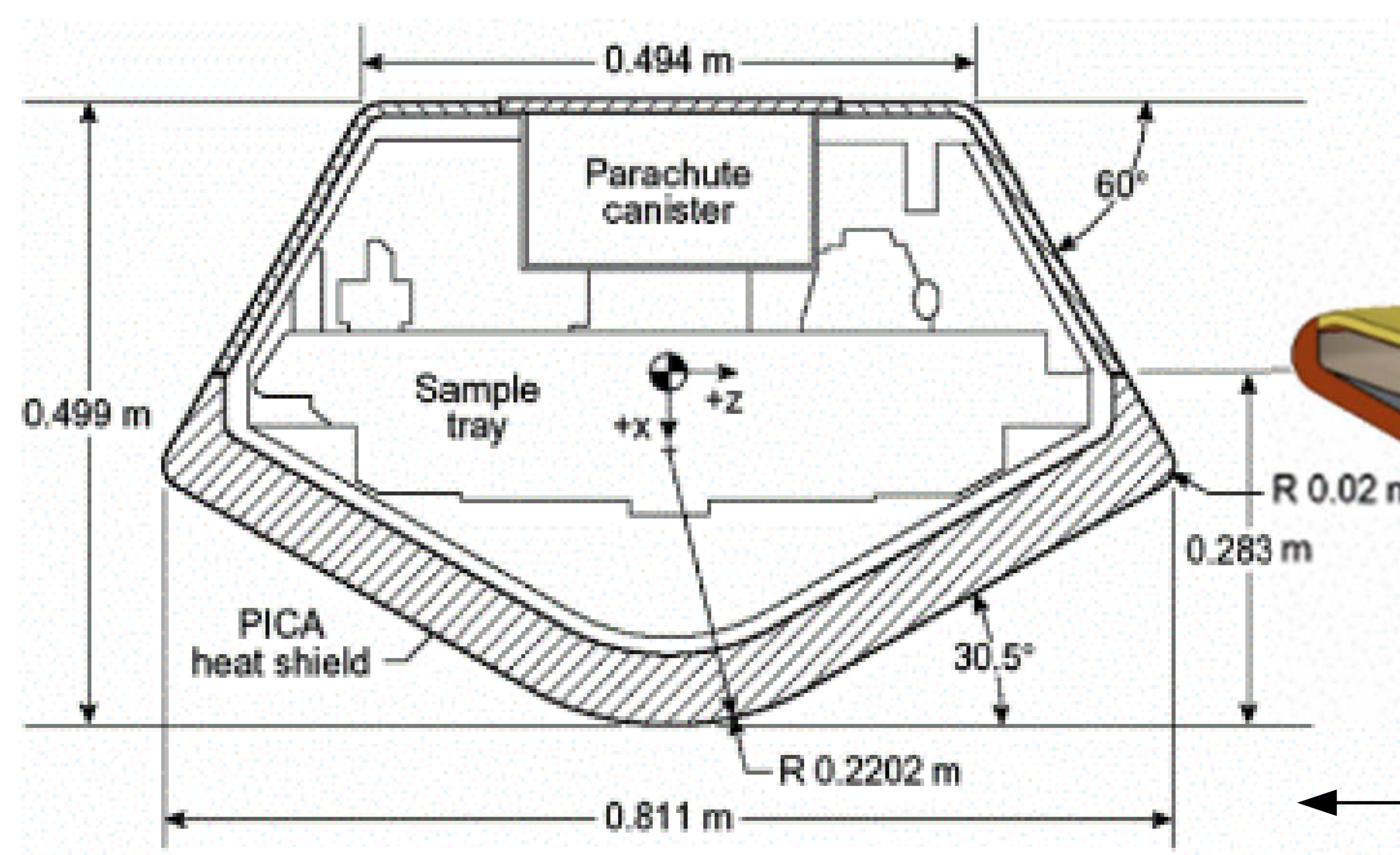
EEV in entry configuration

EEV Design

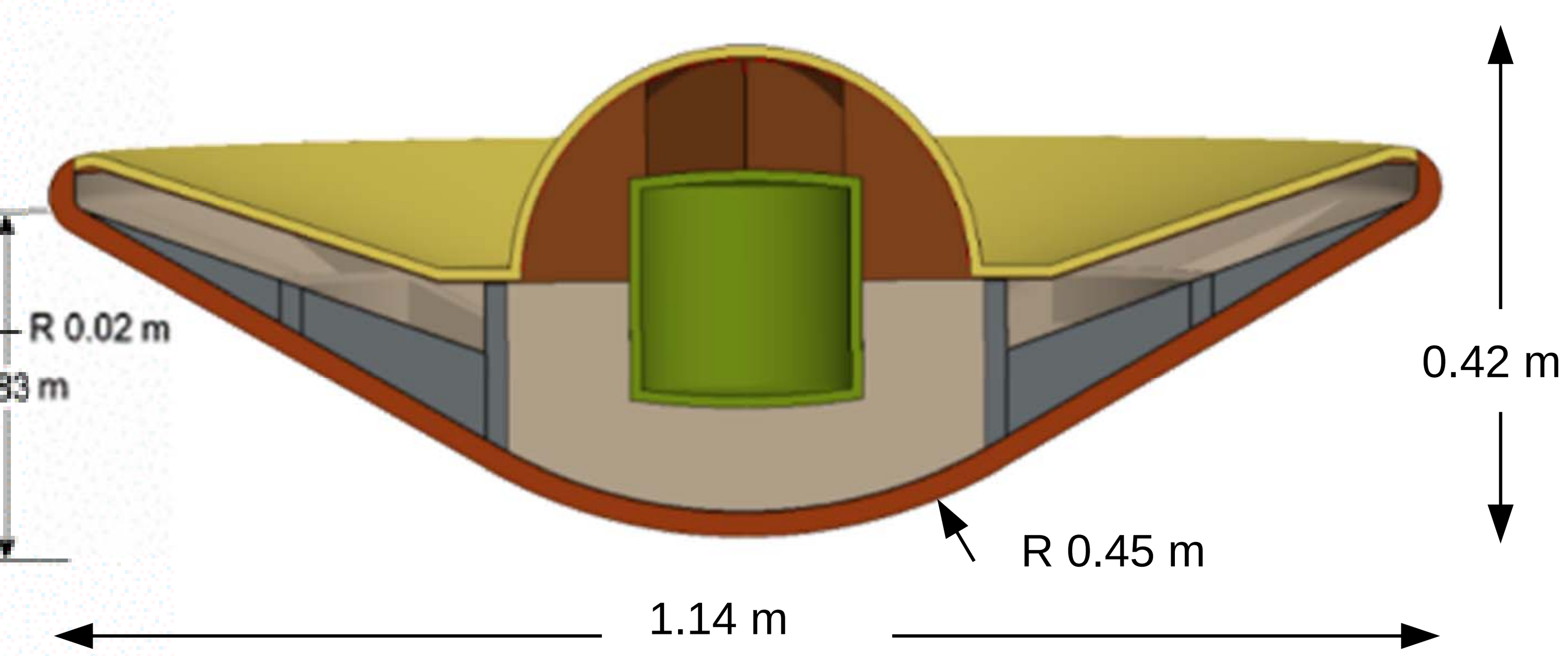
- EEV will enter faster than any NASA sample return mission to date,
  - 14.2 km/s entry speed requires combined convective and radiative heating calculations.
- EEV has a similar mass to OSIRIS-REx but with greater outer diameter.
- EEV trajectory and configuration keeps heating in family with previous sample return missions:
  - Lower ballistic coefficient (β) keeps peak heating low,
  - Higher Entry Flight Path Angle (γ) keeps total heat load low.

CSSR Flowfield Predictions





Stardust Geometry[8]

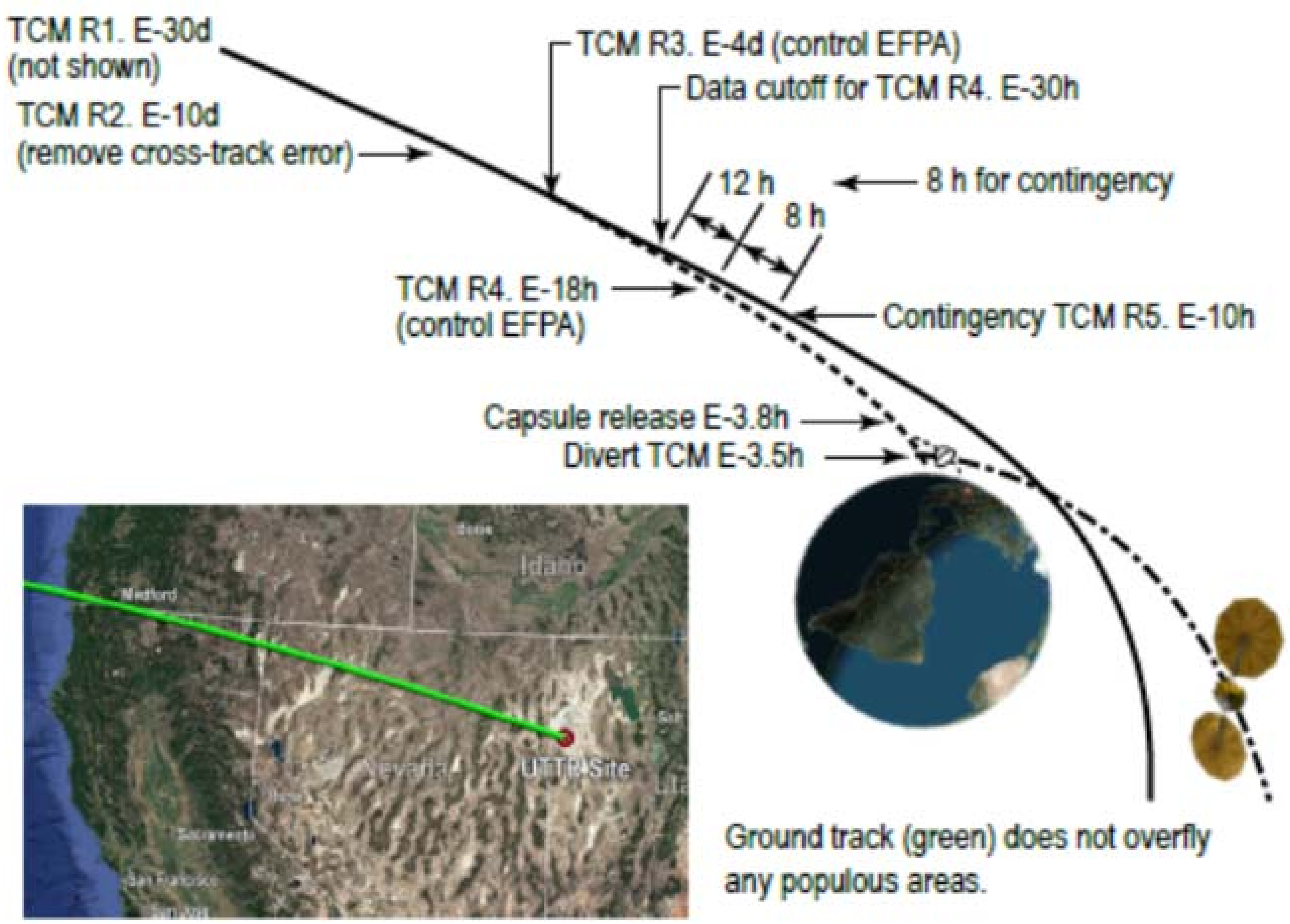


CSSR Geometry

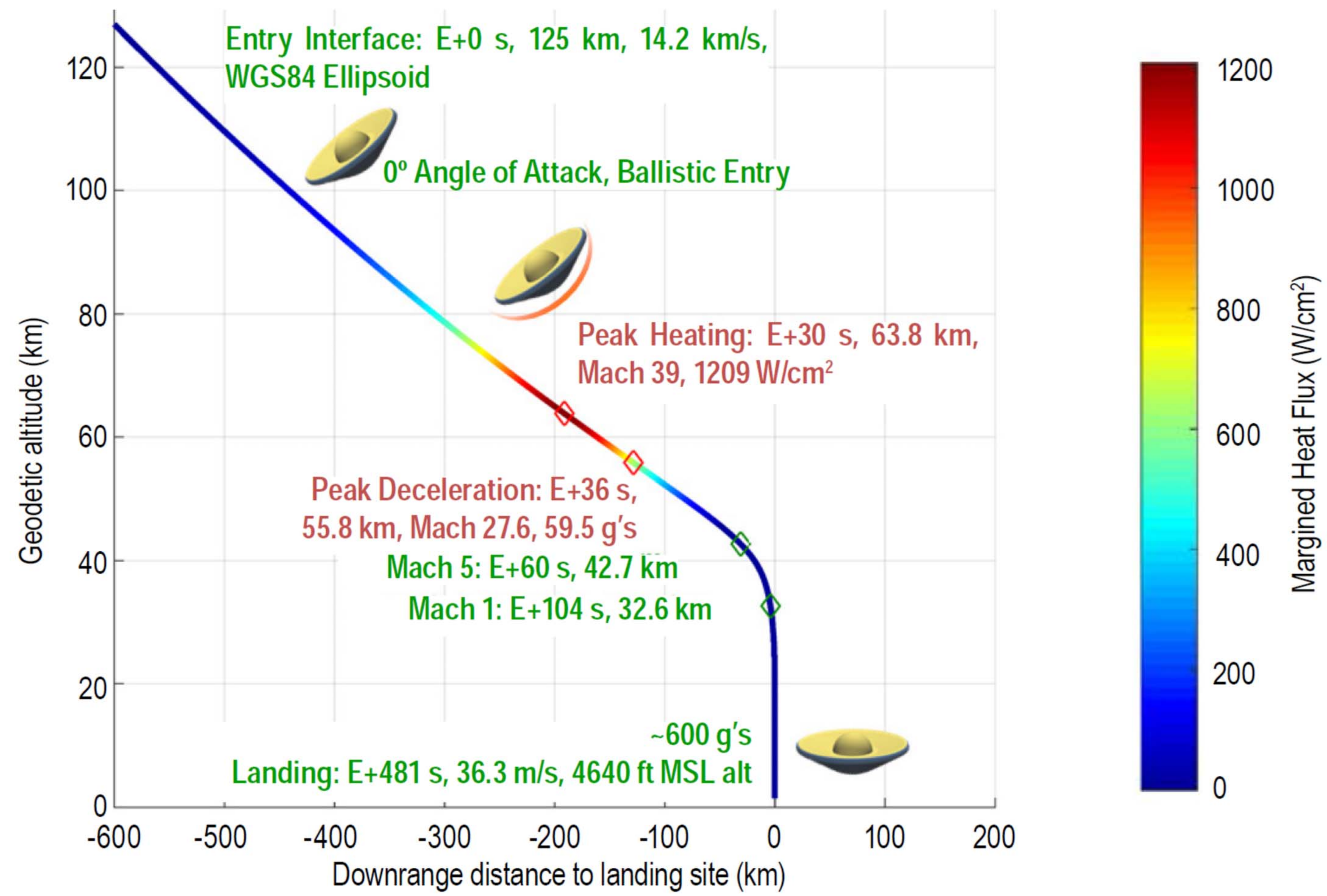
	Stardust / OSIRIS-REx	CSSR
Relative Entry Velocity (km/s)	12.6 / 12.4	**14.2**
Relative γ (deg)	-8.2	-11
Entry mass (kg)	46 / 55	54 (Max)
Diameter (m)	0.81	**1.14**
Ballistic Coefficient β (kg/m²)	60 / 71	**34**
Design q_{peak} (W/cm²)	**~1200**	**~1200**
Design Q_{load} (kJ/cm²)	36	**20**

EEV Approach and EDL

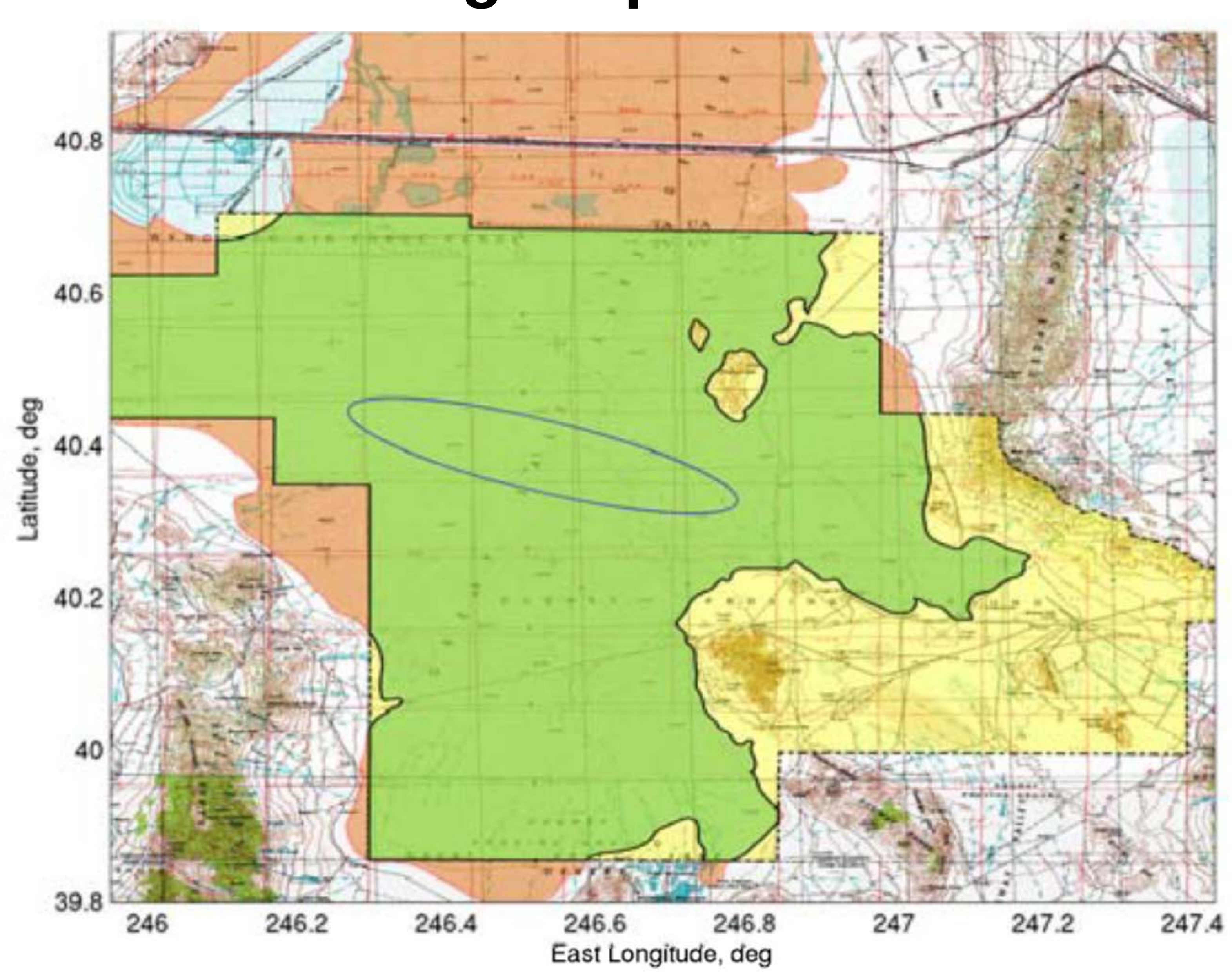
Final Earth Approach Timeline for EEV



EDL Phase Events



Landing Ellipse at UTTR

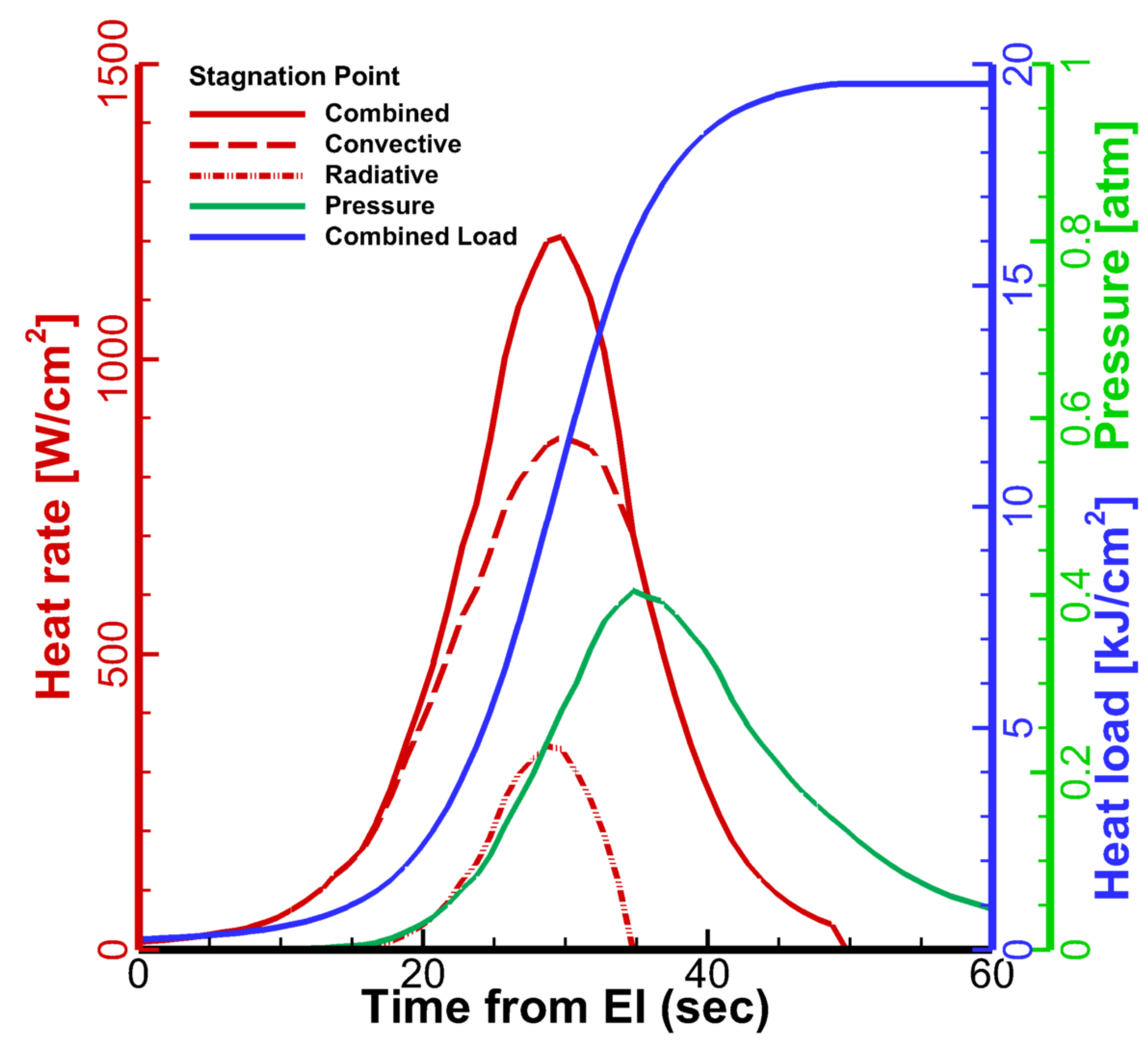


- The EEV will be released from the spacecraft ~4 hours prior to Entry Interface (EI)
- After experiencing peak heating and deceleration, EEV begins subsonic terminal descent ~100 seconds after EI
- The EEV lands at the Utah Test and Training Range (UTTR) eight minutes after EI
  - Lands at ~36 m/s, with payload experiencing ~600 g's.

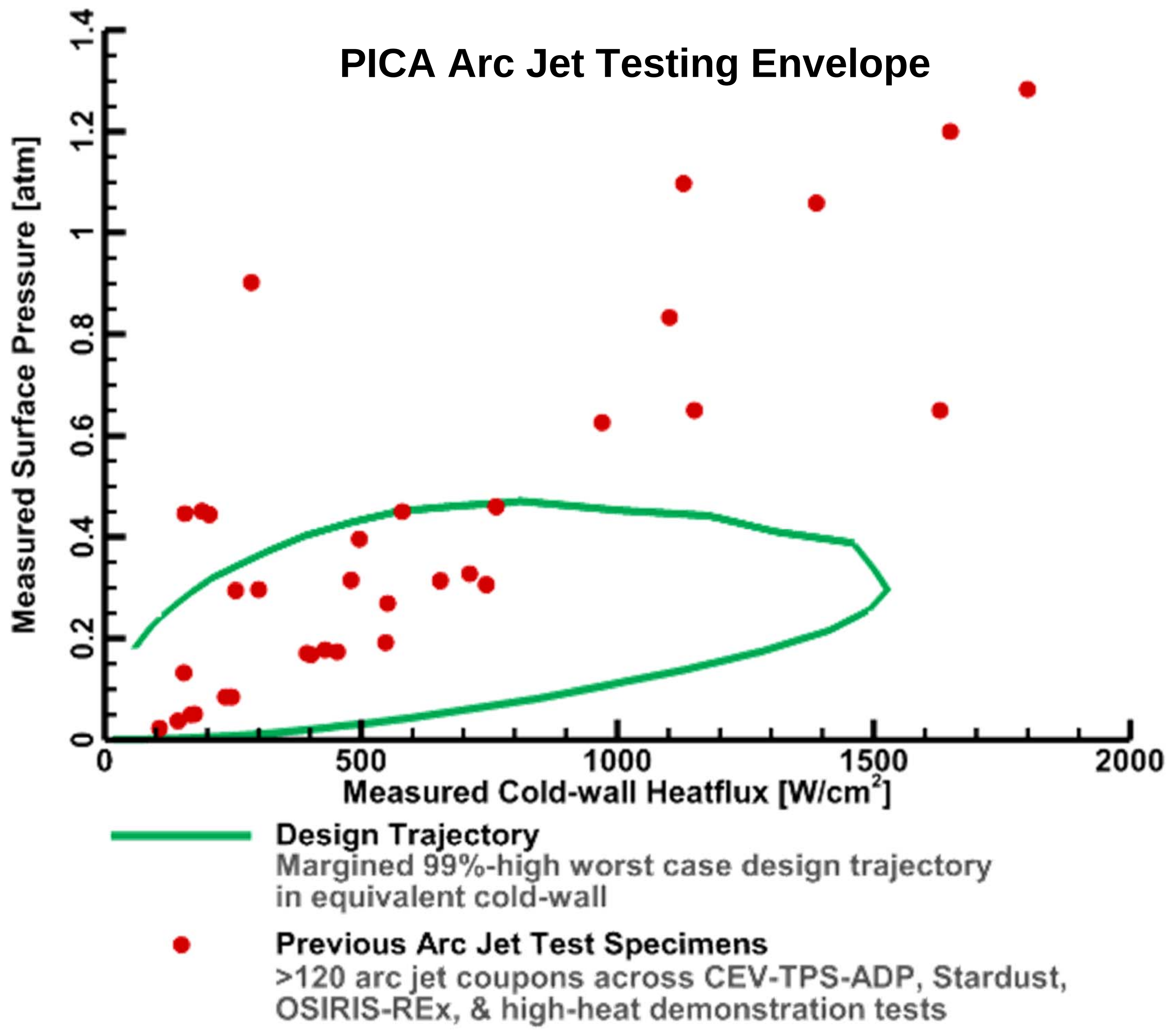
TPS Selection & Sizing

- TPS materials were selected based on margined peak environments.
  - Margins informed by Stardust, OSIRIS-REx & MPCV,
  - All heatshield and aftbody TPS sized to 250 °C bondline temperature limit,
  - Internal payload temperatures remain cold due to low cruise temperatures, rapid heat pulse, and convective cooling on descent.
- **Heatshield TPS**: PICA well within demonstrated environments:
  - Heatshield is single piece; similar scale to MPCV PICA net-cast shoulder TPS demonstrations,
  - PICA has heritage on Stardust, OSIRIS-REx & MSL.
  - EEV uses 1.2” of PICA on heatshield in uniform thickness.
- **Aftbody TPS**: Acusil II is a moldable low-density syntactic silicon. EEV uses Acusil within it’s zero-ablation regime (<<100 W/cm^2)
  - Acusil II has heritage on MSL, ascent vehicles, & ballistic missiles,
  - EEV uses 0.8” Acusil II on lid,
  - EEV uses 0.6” Acusil II on rest of aftbody.

Heatshield Design Environments

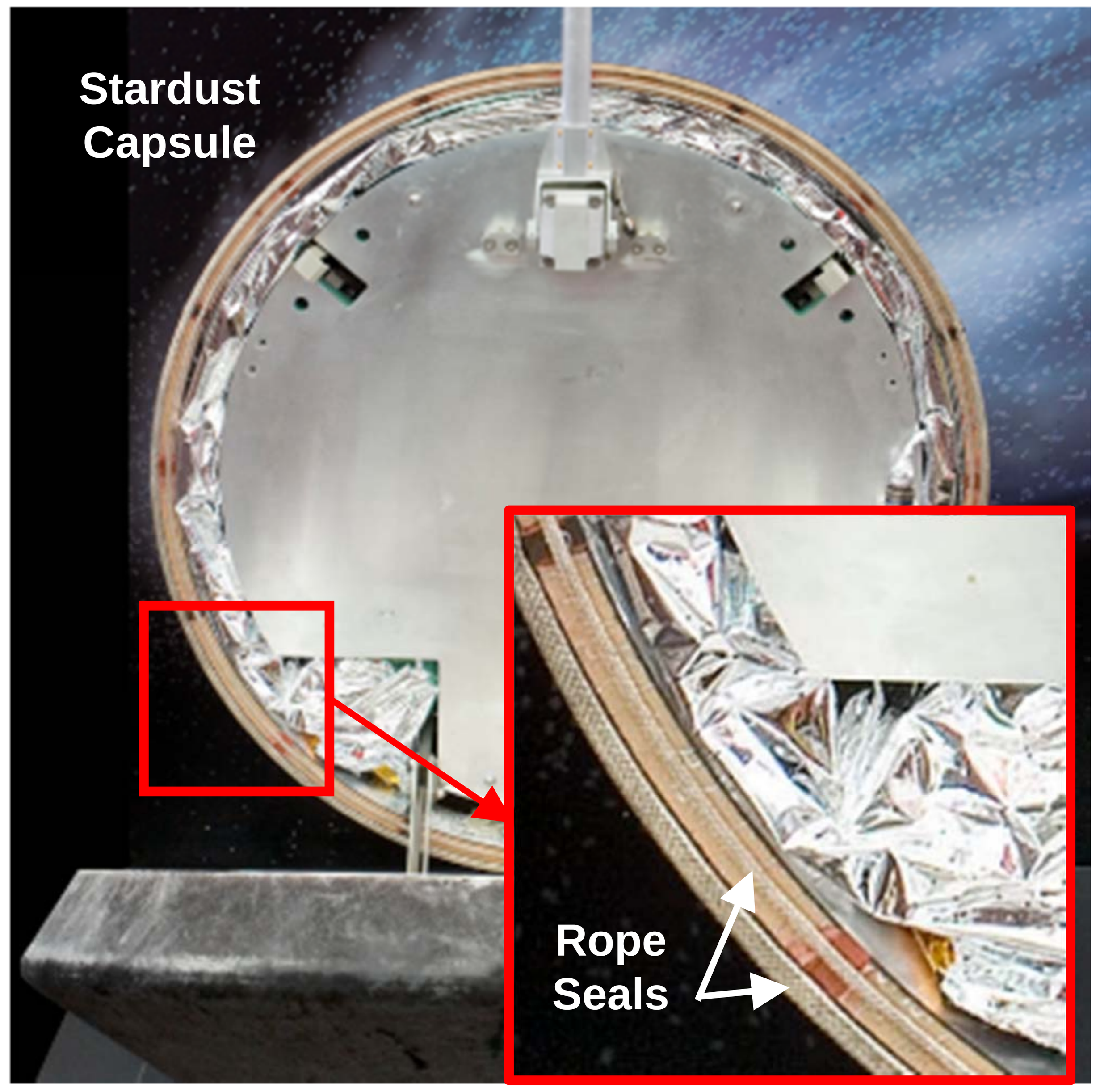


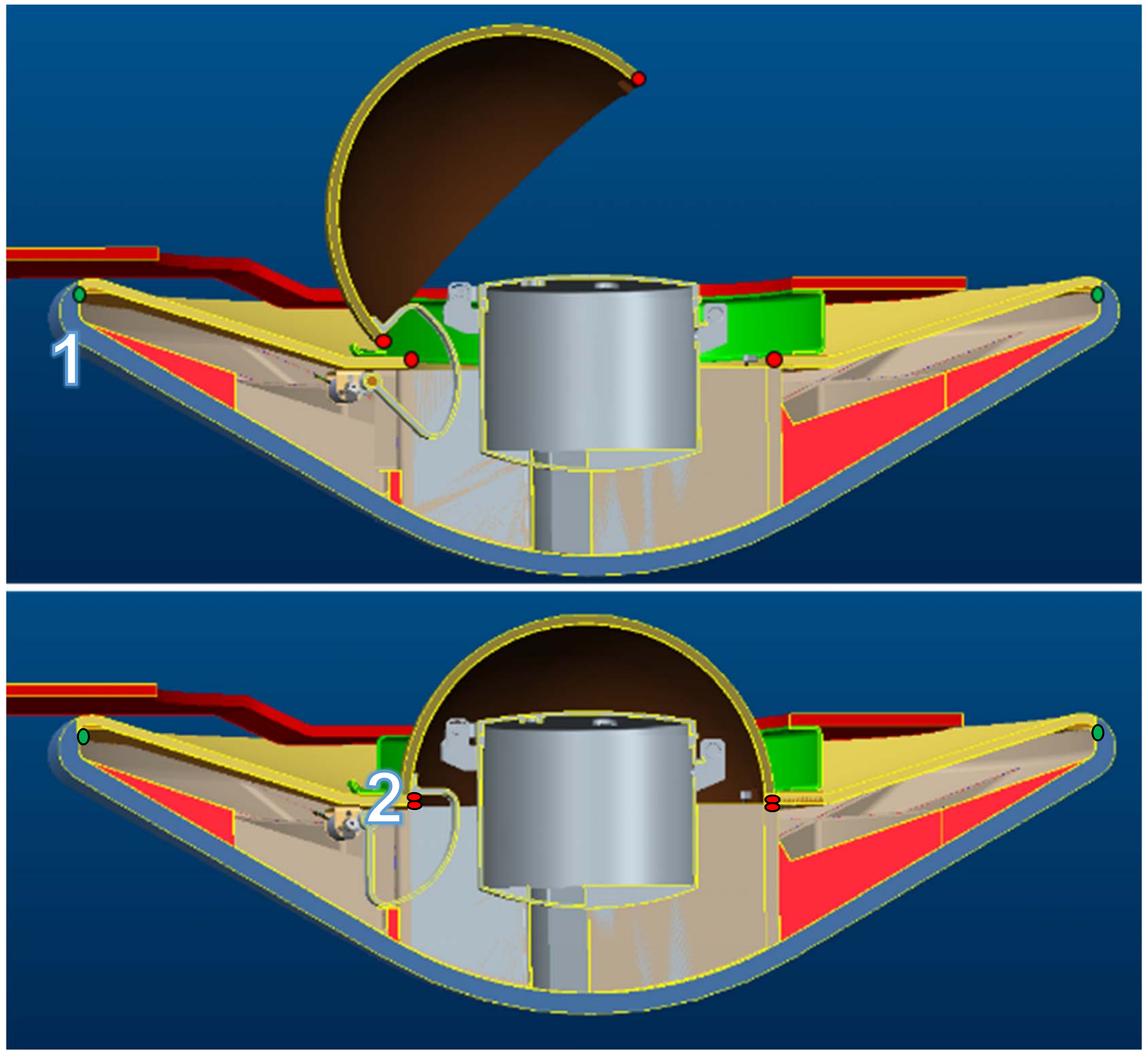
Acusil II on MSL



EEV Lid Closure and Seals

- EEV seals protect against hot gas ingestion during entry.
  - SSS also has redundant hermetic seals for protecting samples from contamination
  - All EEV seals are similar to those used on Stardust, and are within demonstrated capability of rope seal material (heating < 30 W/cm^2).
- EEV has two locations with non-hermetic seals:
  - 1) Rope seal is between forebody PICA to aftbody Acusil II:
    - Lies in a recessed groove in the PICA and Acusil II at the mating interface.
  - 2) Rope seals to seal aft lid interface:
    - Operates during open and close cycles of the EEV lid during mission operations.
- The lid is attached via an offset hinge:
  - Provides wide clearance to the payload canister (over 100º of rotation),
  - Hinge is actuated by two motors, one to open and one to latch the aft lid.



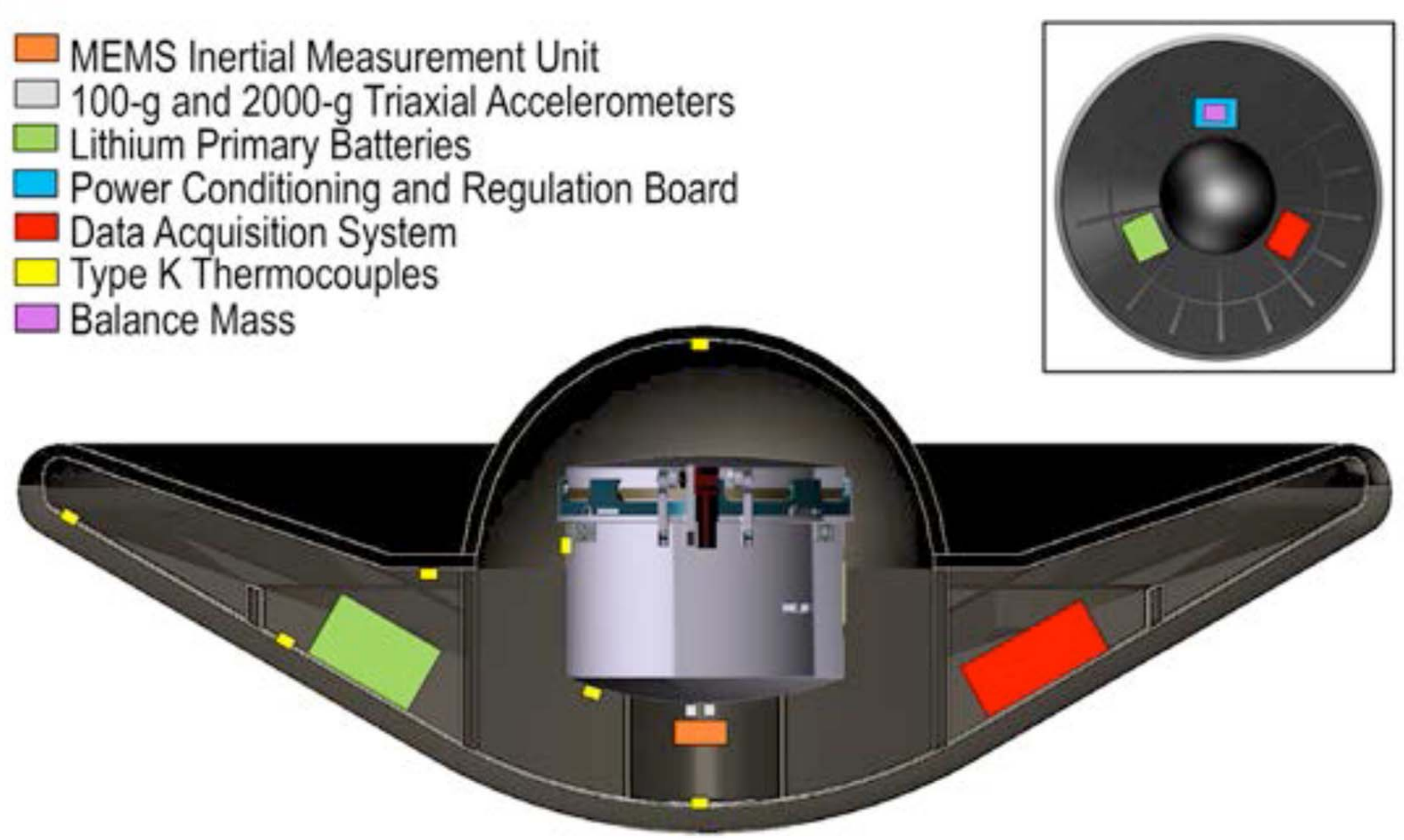


Offset hinge operation and seal locations

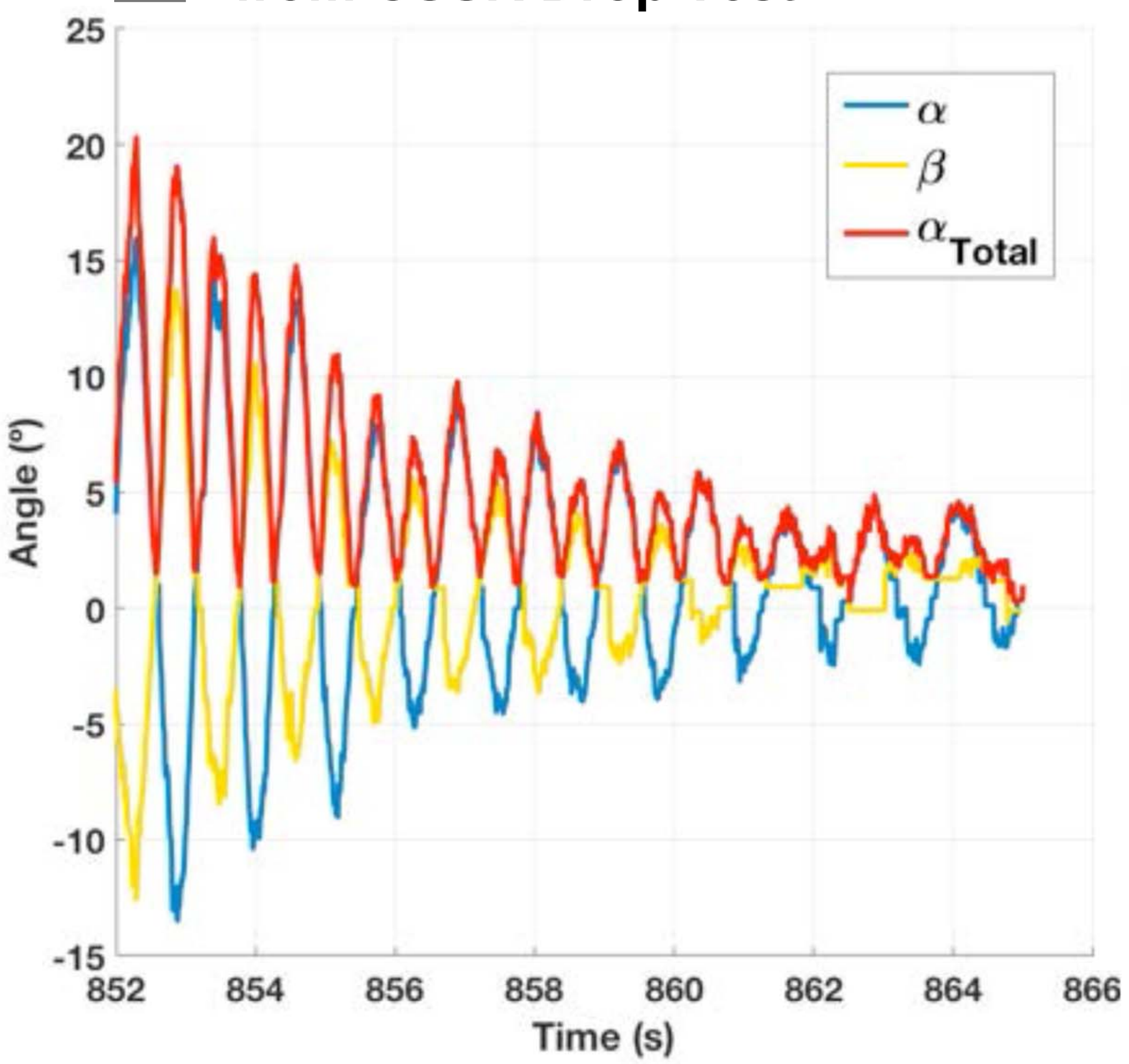
EDL Instrumentation

- An Engineering Science Investigation (ESI) will record sensor data on EEV performance, environments, and provide diagnostics.
- CSSR's EEV includes commercial sensors and supporting electronics (batteries, data acquisition system) to record:
  - Entry inertial measurements,
  - Landing loads,
  - Internal capsule & payload temperatures.
- Value of these measurements demonstrated during UTTR drop[6] and thermal cycle testing.

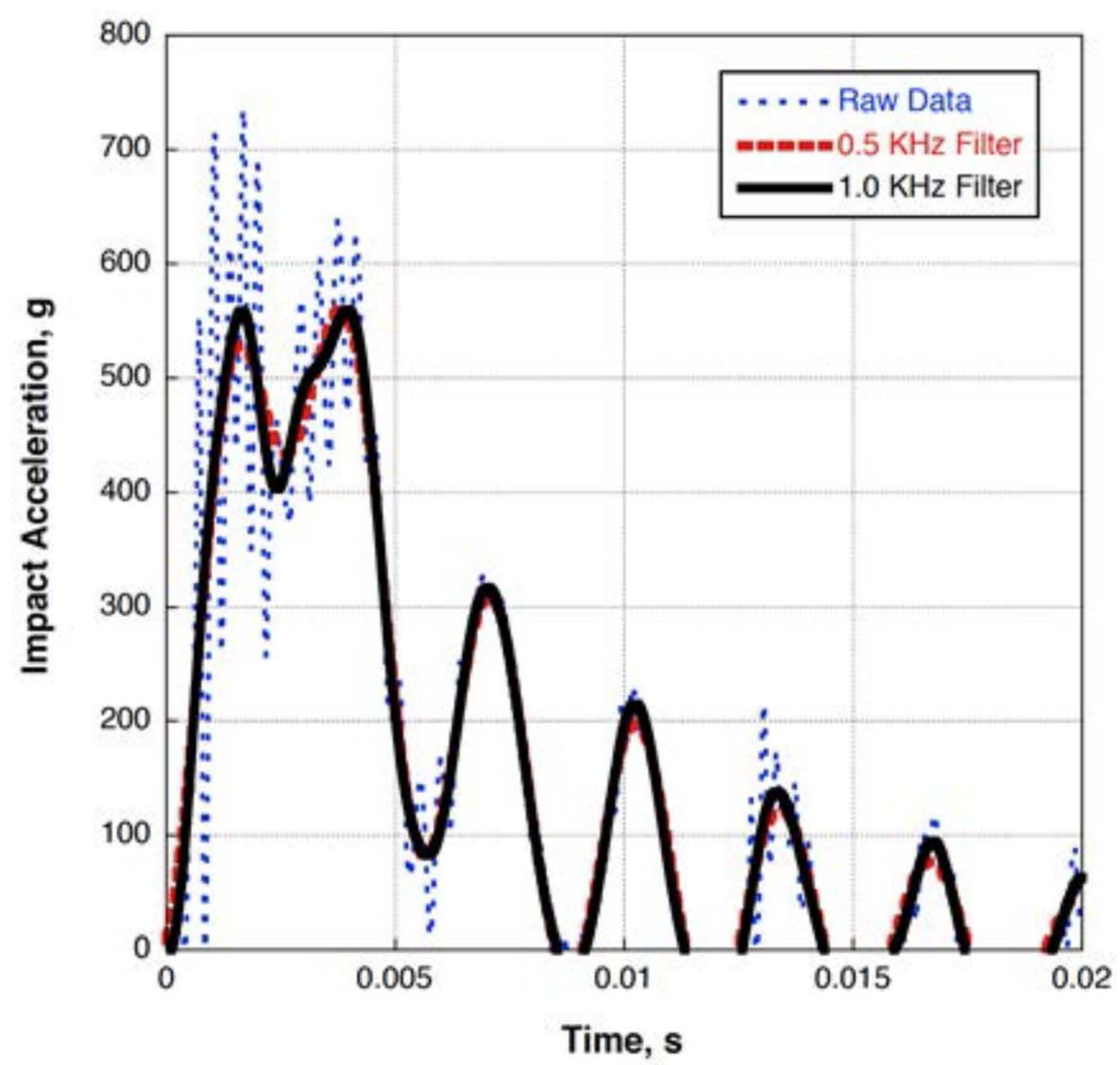
CSSR EDL Instrumentation



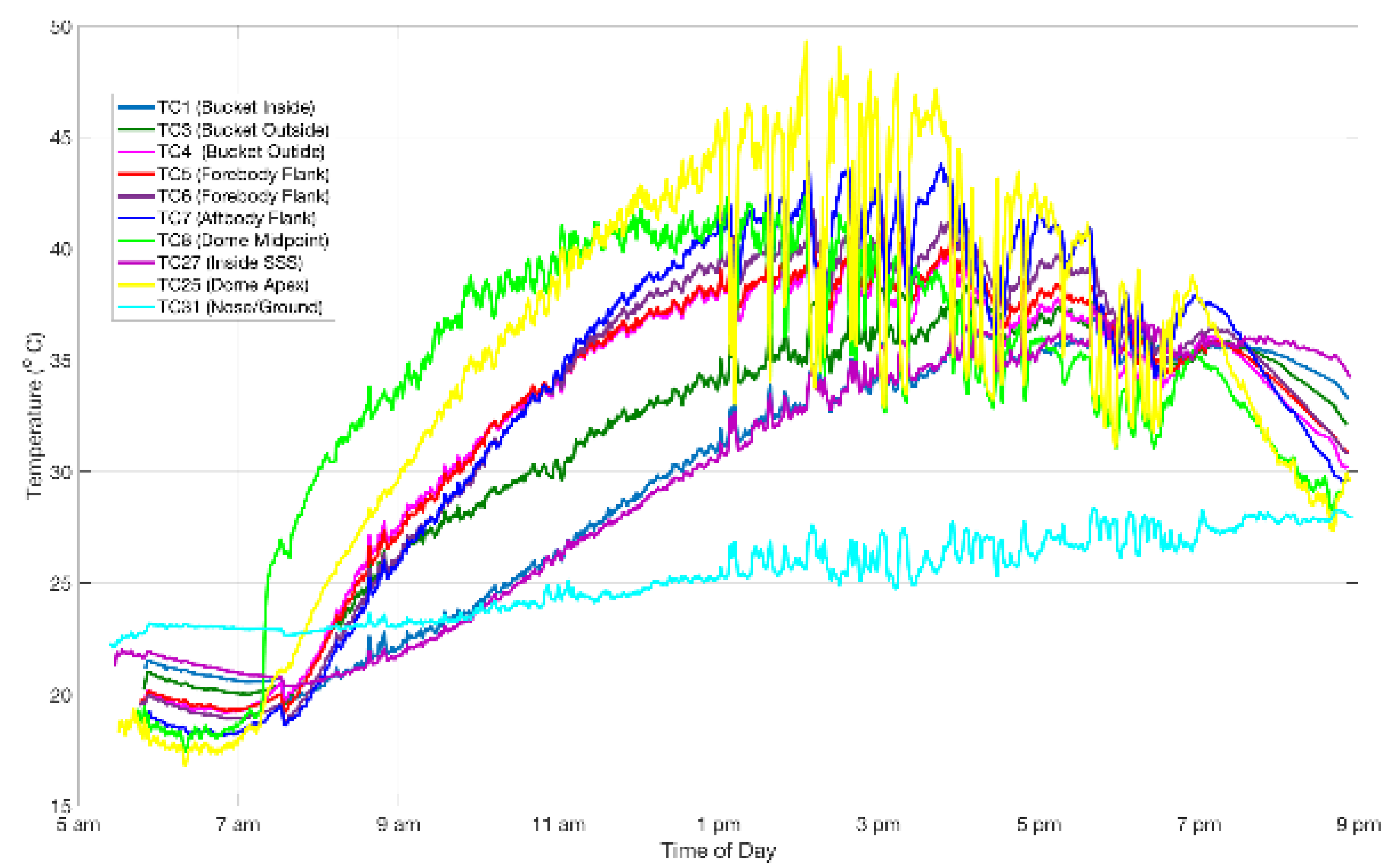
Reconstructed Vehicle orientation from CSSR Drop Test



Peak Impact Deceleration



Internal Temperatures



Summary

- A 1.14 m diameter chuteless Earth Entry Vehicle was designed for the Comet Surface Sample Return mission.
  - A low-ballistic coefficient keeps entry conditions at or below those of OSIRIS-REx, even with a 14.2 km/s entry velocity.
- TPS was selected and sized to design entry environments,
  - Both heatshield and aftbody materials with flight heritage.
- EEV aft lid was designed to permit easy access to payload.
- EDL instrumentation system was developed to gather vehicle performance data with COTS sensors.
  - Sensor measurements were demonstrated at EEV UTTR landing site.



National Aeronautics and Space Administration

Ames Research Center
Entry Systems and Technology Division

Backup Material

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4. Maddock, R., Henning, A., Samareh, J., “Passive vs. Parachute System Architecture for Robotic Sample Return Vehicles,” in Aerospace Conference, 2016 IEEE, Big Sky, MT Paper 2-0602, February 2016.
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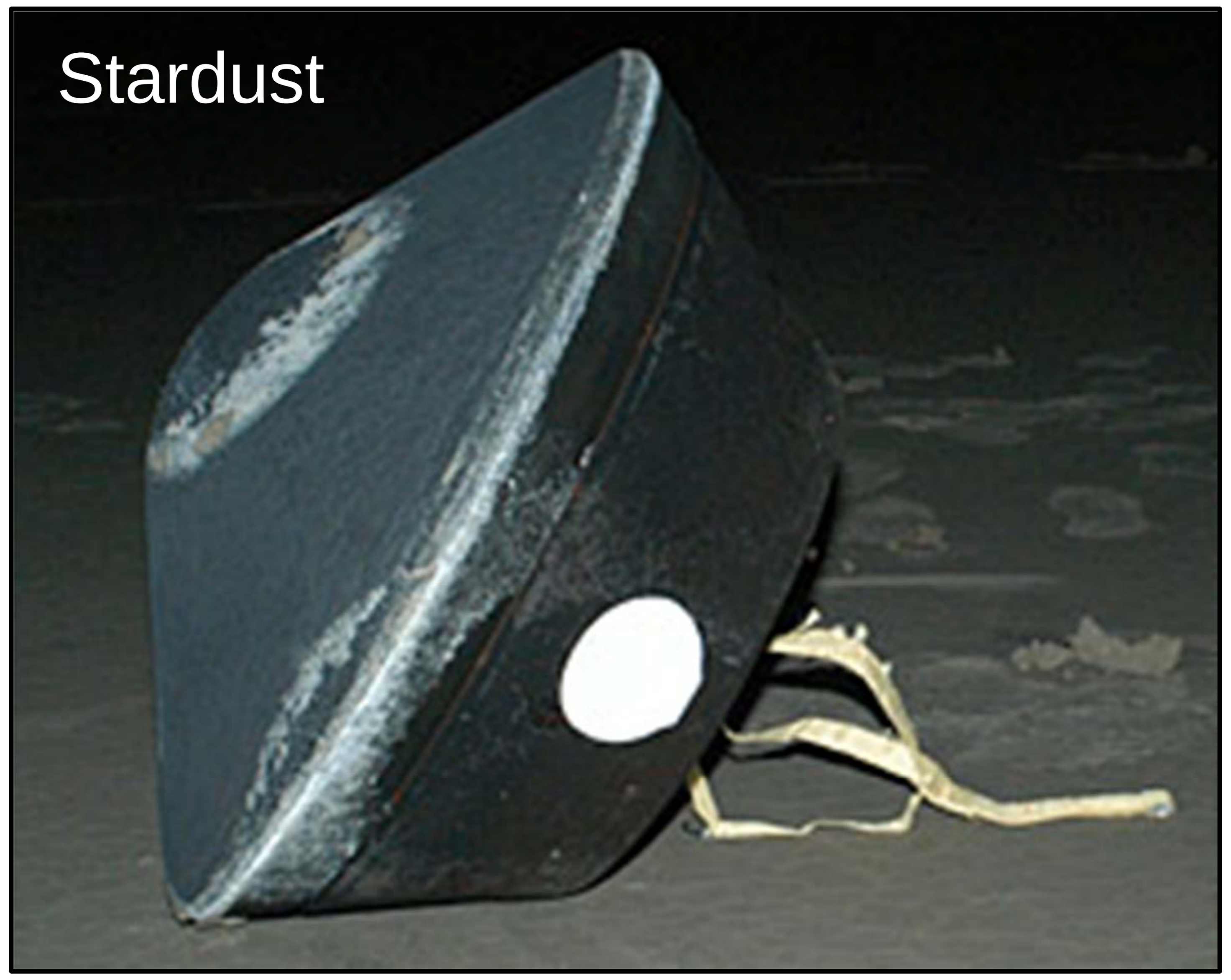
Submitted Abstract

- The 2013 Decadal Survey for New Frontiers missions identifies several high-value science missions, including Comet Surface Sample Return (CSSR). A CSSR mission will advance the scientific community's fundamental understanding of the origin of the solar system and the contribution of comets to the volatile inventory of the Earth. An entry capsule, or earth entry vehicle (EEV), is be required to protect the scientific payload from the extreme conditions of atmospheric entry, descent, and landing.
- The Decadal Survey Mission Concept Study, along with an APL 2007-2008 Comet Surface Sample Mission Study details several of the driving requirements for a CSSR EEV; these include a payload volume and mass and inertial entry velocity of ~ 9 km/s. The mission concept study selected a Multi-Mission Earth Entry Vehicle (MMEEV) design concept derived from the Mars Sample Return (MSR) entry capsule design because of its increased reliability over a parachute-based vehicle. This presentation will explore detailed design of a CSSR-capable Earth Entry Vehicle, including trajectories, aeroheating predictions and associated thermal protection system masses, and onboard instrumentation for entry science.

Terminal Descent & Landing

- Maddock[4] detailed the two sample return landing architecture types:
  - Active: System that deploys a deceleration system, such as a parachute.
    - Lower landing velocity (and g's), less reliable due to additional parachute complexity,
    - Missions: Stardust, Genesis, OSIRIS-REx
  - Chuteless: Aerodynamic deceleration provided by the drag of the entry vehicle itself.
    - Attributes: Higher landing velocity (and g's), higher system reliability,
    - Missions: Mars Sample Return (MSR), MMEEV,
  - Choice of architecture is governed by mission requirements, including **sample preservation and recovery**.


Stardust


Genesis


MSR (Drop Test Demonstration)