A Neptune Orbiter Concept using Drag Modulated Aerocaptue (DMA) and the Adaptable, Deployable Entry and Placement Technology (ADEPT)

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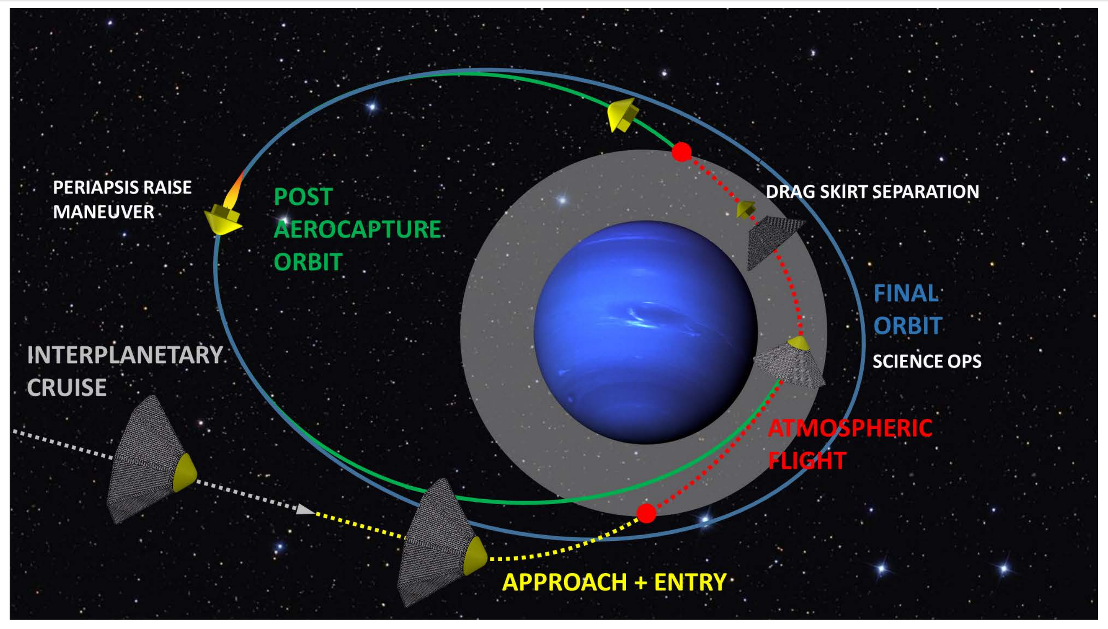
Background – What is Drag Modulated Aerocapture (DMA)?

- Aerocapture uses the drag from a single pass through the atmosphere of a planetary body to slow down and enter orbit, rather than a large burn from a propulsion system.
- Drag modulation flight control is used to reach a specific orbit in the presence of targeting and atmospheric uncertainties.
  - By modulating the time that a drag skirt is jettisoned from the spacecraft, the vehicle can control the amount of delta-v received.

Aerocapture Mission Benefits

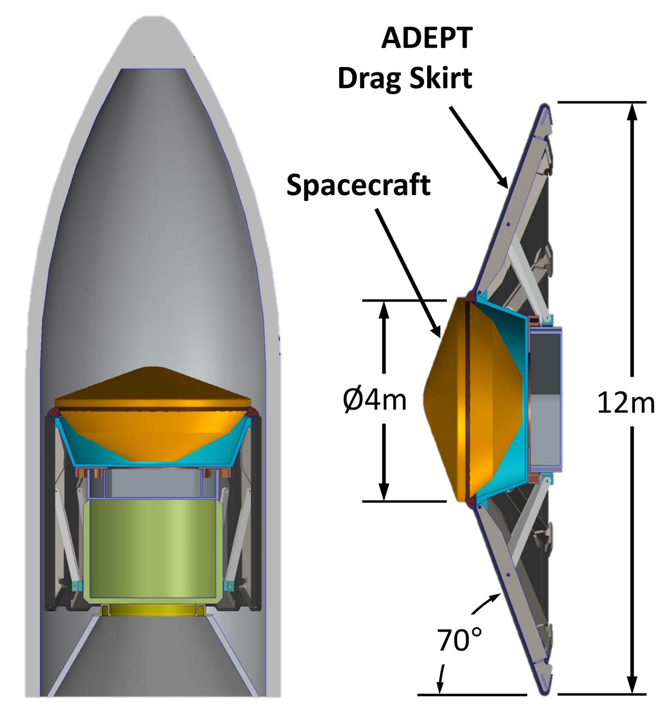
- **Greater mass efficiency** – lower propellant mass can leave more room for payload or enable missions with different launch vehicles.
- **Shorter trip time** – the spacecraft can travel faster and arrive at a greater speed relative to the planet without a propulsive penalty to slow down and enter orbit.



Conceptual Neptune Orbiter using DMA

- Conceptual Neptune orbiter was designed for the purpose of assessing mission feasibility
  - Built off of the 2017 Pre-Decadal Study, but adapted for drag modulation aerocapture.
  - Science payload includes: Narrow Angle camera, Doppler Imager, Magnetometer, Atmospheric Probe (w/ ASI, Nephelometer, Mass Spectrometer).
  - Baseline concept of operations releases probe prior to orbit insertion, but investigations are ongoing to assess the feasibility of bringing the probe to orbit before release.
- 70 degree sphere-cone geometry chosen as starting point because of high heritage and good understanding of aerodynamics (Viking, MER, MSL, M2020).
- 12m ADEPT drag skirt is stowed for launch, facilitating fit within 5 meter launch vehicle fairing.
  - ADEPT drag skirt is jettisoned during atmospheric pass and the orbiter is released from the aeroshell after exiting the atmosphere.
- The vehicle targets a 430,000 km apoapsis orbit, to allow for Triton flybys.

Neptune DMA Concept with ADEPT
(Stowed in 5m Fairing) - (Deployed for Entry)



Conceptual Flight System Design Assumptions*

	Mass	Ballistic Coefficient
Atmospheric Entry	5725 kg	30 kg/m²
Atmospheric Exit	2580 kg	121 kg/m²
Orbiter	1480 kg	N/A

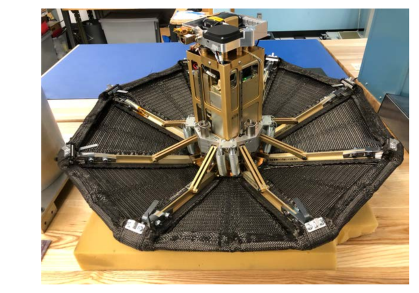
*Many opportunities exist for further flight system optimization

Ballistic Coefficient Ratio:
$\beta_1/\beta_2 = 4$

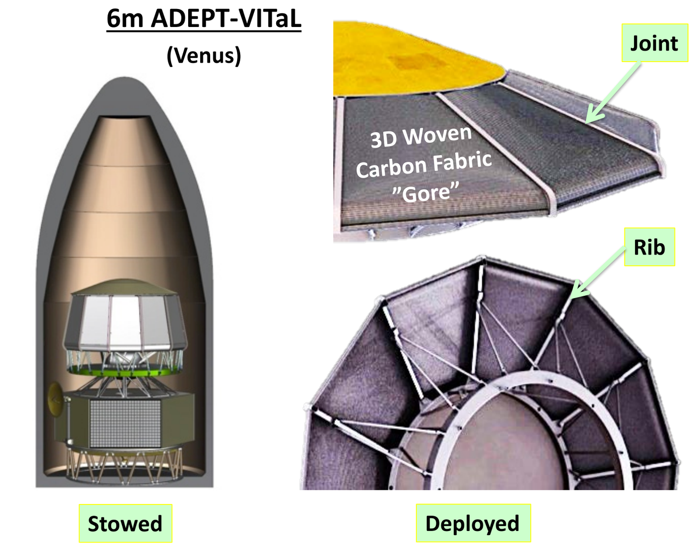
Background – What is ADEPT?

- **ADEPT** is an atmospheric entry *architecture* for missions to most planetary bodies with atmospheres.
  - Current Technology development project funded under STMD Game Changing Development Program (FY12 start)
  - Stowed inside the launch vehicle shroud and deployed in space prior to entry.
  - Low ballistic coefficient provides a benign deceleration and thermal environment to the payload.
  - High-temperature ribs support 3D woven carbon fabric to generate drag and withstand high heating.

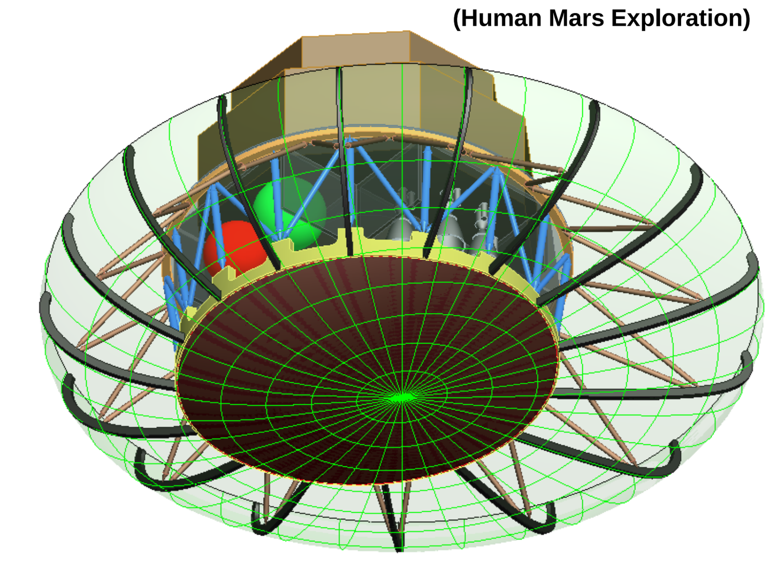
0.7m ADEPT SR-1
Earth Flight Test (Mach 3)
Sept 2018



6m ADEPT-VITaL
(Venus)

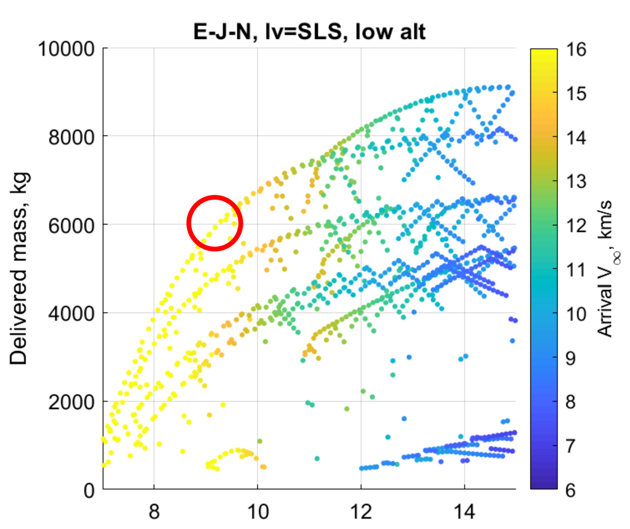


16m Lifting ADEPT
(Human Mars Exploration)



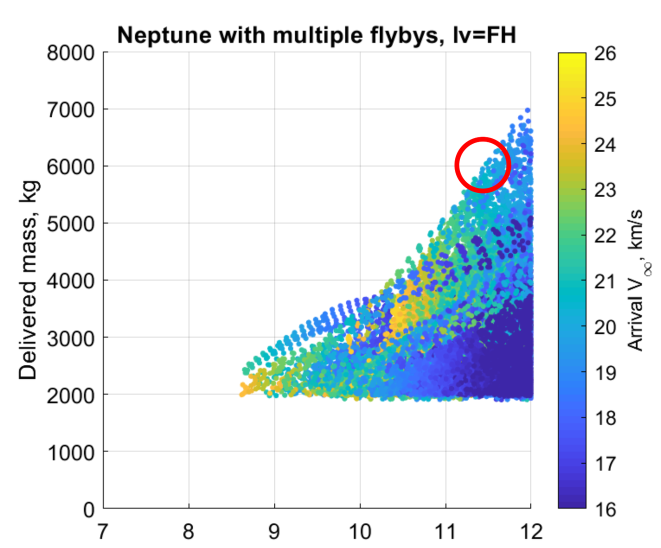
Interplanetary Trajectory Design for Neptune Orbiter

- A broad trajectory search was conducted for launch dates in the late 2020's to mid 2030's
- Launch vehicles considered were SLS Block 1B and Falcon Heavy
- 6,000 kg delivered mass was the focus, but opportunities to optimize the flight system mass can result in significantly shorter flight times



Trajectory search for an SLS Block 1B launch with Jupiter flyby

- The ~6,000 kg delivered mass region contains trajectories with flight to Neptune in ~9 years.
- Arrival V-infinity of ~16 km/s results in conventional chemical propulsion orbit insertion delta-v of ~5 km/s, which is likely not possible.
- Comparable chemical propulsion trajectories exist for 12-13 year flight time. **Aerocapture starts science mission 3-4 years sooner.**

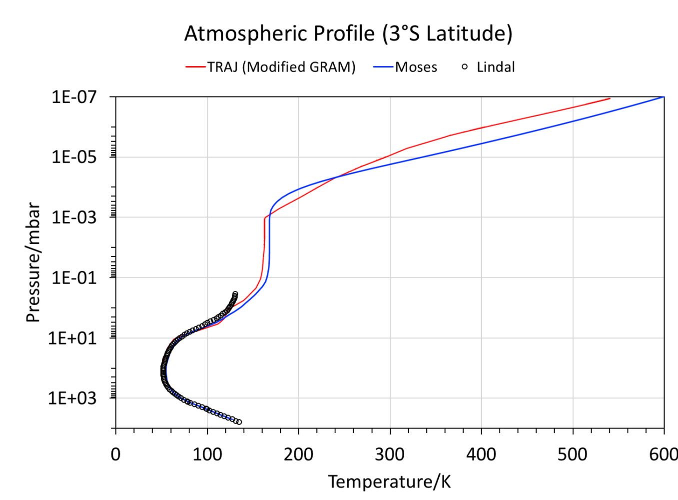


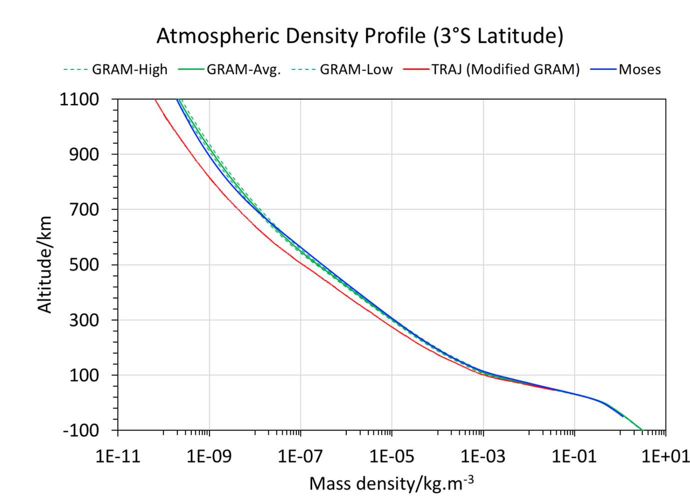
Trajectory search for a Falcon Heavy launch with multiple flybys

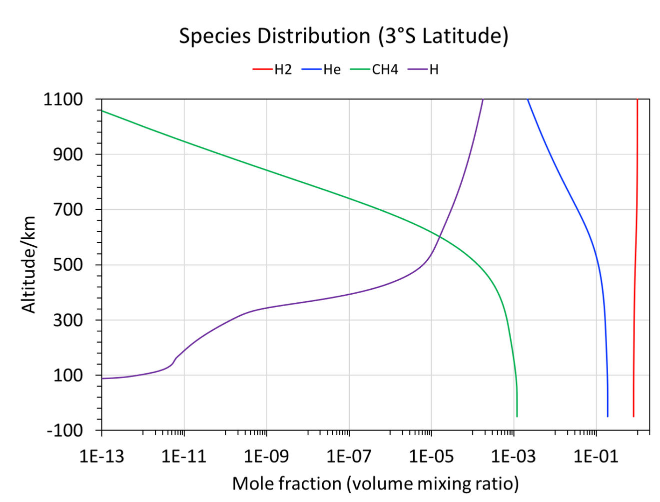
- The ~6,000 kg delivered mass region contains trajectories with flight to Neptune in ~11.5 years.
- Arrival V-infinity of ~18 km/s results in conventional chemical propulsion orbit insertion delta-v of ~6 km/s, which is likely not possible.
- Comparable chemical propulsion trajectories do not exist for reasonable flight times. **Aerocapture is the only way to achieve orbit with this launch vehicle on a purely chemical trajectory (i.e. no SEP stage).**

Neptune Atmosphere Module used in DMA Simulations

- Modified version of Neptune GRAM used in trajectory simulations
  - Modifications result in lower density
- Actual GRAM profile compares very well with data from Moses *et al.* (*Icarus*, 307, pp.124-45, 2018)
- Atmospheric composition held constant at H_2:He = 0.85:0.15 (by vol.)
- Aeroheating occurs in the stratosphere





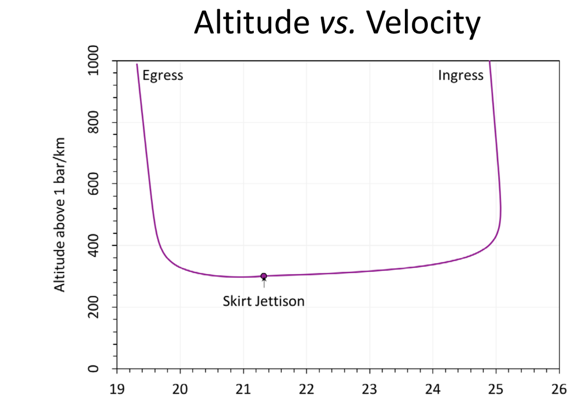


Neptune DMA Trajectories and Preliminary Aerothermal Analysis

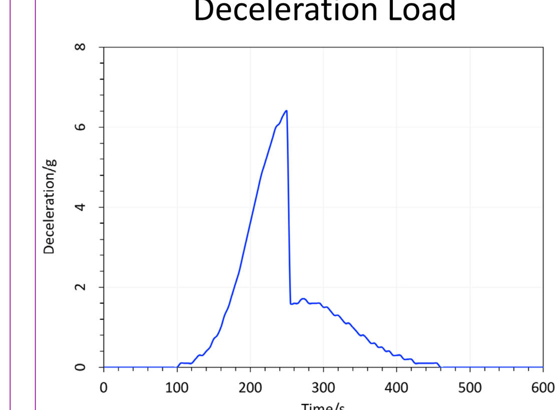
Preliminary DMA Trajectory and Stagnation Point Aerothermal Environments

- Configuration(s) with R_{nose} = 1 m
  - 12 m (dia.) 70° sphere-cone (with ADEPT skirt)
  - 4 m (dia.) 70 deg sphere-cone (without ADEPT skirt)
- 3DOF trajectory developed using *TRAJ* for entry state:
  - Equatorial, posigrade entry
  - m_E = 4000 kg, V_E (inert.) = 28 km/s, g_E (inert.) = -10.9°,
  - ADEPT skirt jettison at 252 s
  - $m_{@Jettison}$ = 1800 kg, Aerocapture apoapsis ≈ 430000 km
- Stagnation point aerothermal environments from engineering correlations; no radiative heating

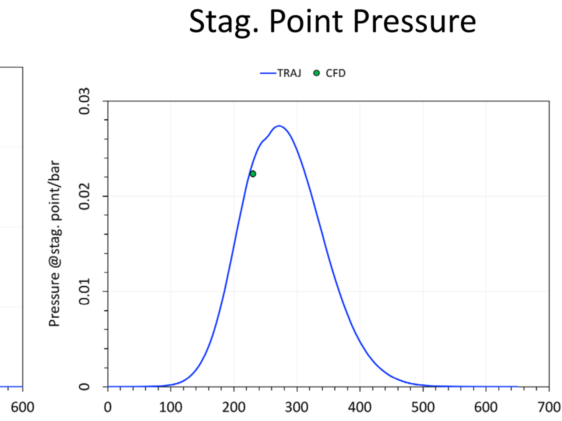
Altitude *vs.* Velocity



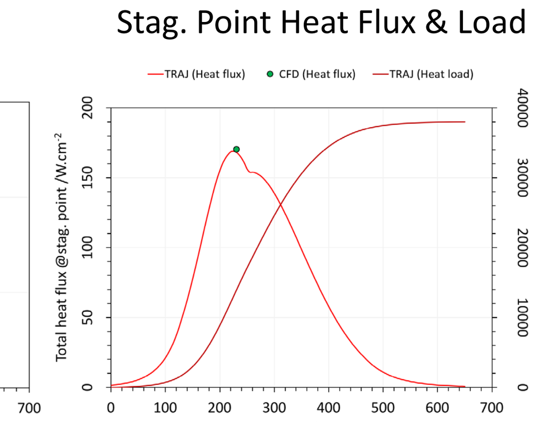
Deceleration Load



Stag. Point Pressure

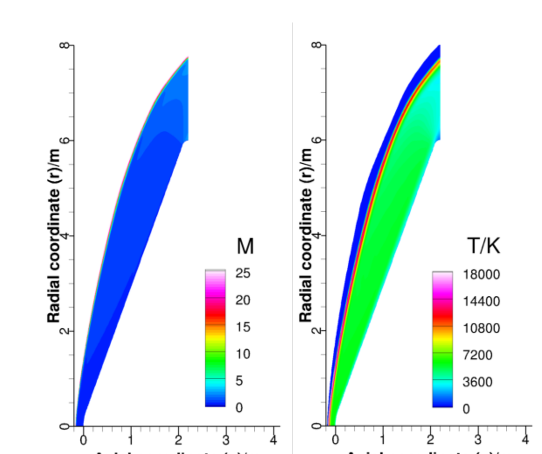


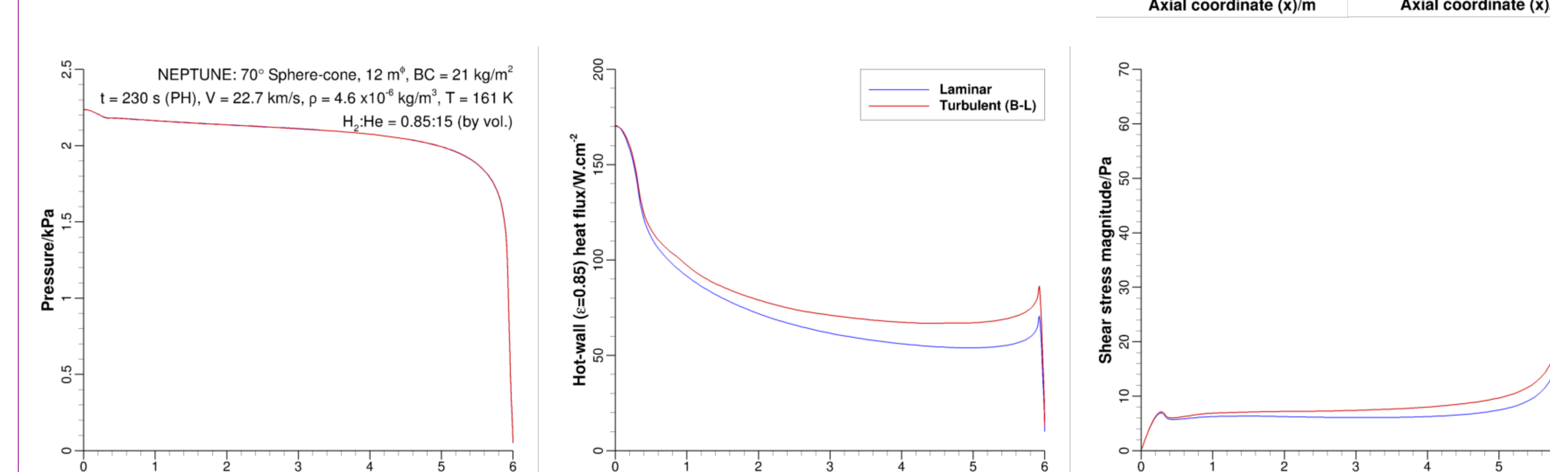
Stag. Point Heat Flux & Load



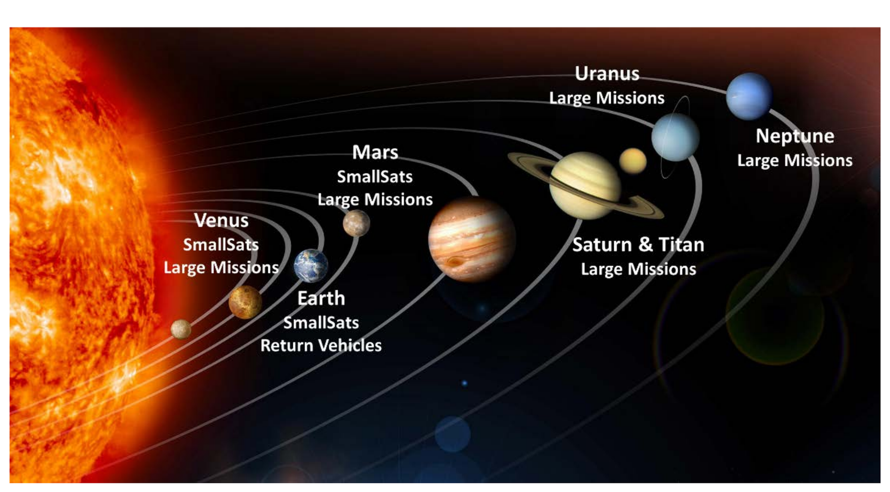
Distributed Aerothermal Environments (at Peak Heating Point)

- Distributed aerothermal environments using *DPLR* (v4.04)
- 7-sp (H_2, He, H, H_2^+, H^+, He^+, and e^-) gas model
- Both laminar & turbulent flow simulations
- Wall assumed fully catalytic with emissivity of 0.85
- Predicted stagnation point pressure and heat flux compare very well with estimates from engineering correlations
- Distributed aerothermal environments used in sizing TPS material for rigid nose, and carbon fabric (ADEPT skirt)



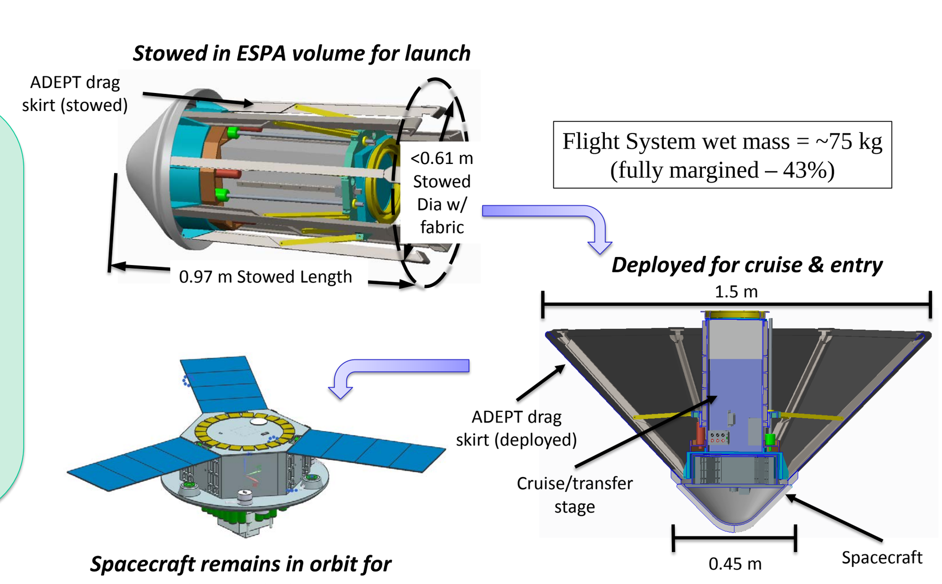


DMA for small and large missions across the solar system



Drag modulation aerocapture creates a capability across the solar system, for both small and large missions

A SmallSat for Venus and Mars applications can enable a new class of small science missions while demonstrating the key technologies for aerocapture with a much larger mission



Open Questions and Future Work

- Exploration of expected orbit targeting accuracy with the drag modulation system at Neptune in the presence of uncertainties (previous work has shown that orbit targeting accuracy is sufficient at Venus, Mars, and Titan)
- More in-depth flight system design and optimization
- Further analysis to refine mass estimates of ADEPT system needed
- Continued work towards flight of the SmallSat system as a pathfinder for a future large mission
- Assessment of science instruments and mission objectives (eg Triton observations and delivery of atmosphere probes from Neptune orbit) will be needed to further refine payload mass and volume requirements

Summary

- Drag modulation aerocapture creates a **new capability** to change how we do missions across the solar system
- Key benefits include **greater mass efficiency** and **decreased flight time** to planetary destinations
- Preliminary Neptune DMA entry vehicle configuration shows **Mars-like entry heating** environments that could result in lower risk TPS options enabled by ADEPT drag skirt