

2024 Planetary Science Technology Symposium

Aerocapture Demonstration Mission at Earth

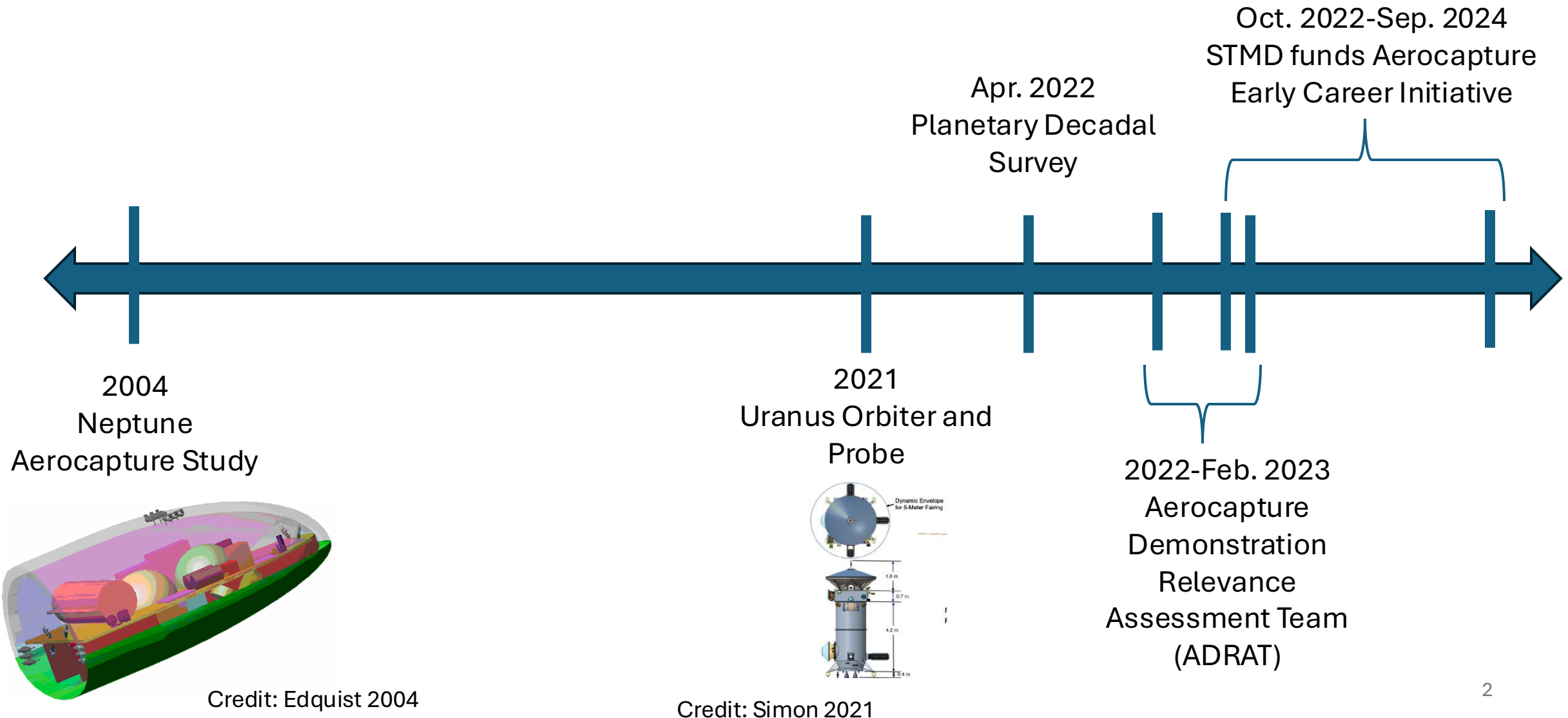
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Timeline



ADRAT Risk List

	Risk Statement	Type	Level of Risk
1	If the atmospheric density profile uncertainty is too large, then trajectory or flight-path calculations based on the blunt-body heritage would be in error.	Development	High
2	If the aerocapture implementation heat shield TPS performance and sizing requires more mass than studies assumed, then the dry mass will exceed the allocation.	Development	Low
3	If the aerocapture implementation requires more mass for ancillary systems (e.g., g-load mitigation, separation mechanisms, packaging, heat dissipation), then the dry mass will exceed the allocation.	Development	Medium
4	If the aerocapture uncertainties are too high, then the cost (\$, mass) of implementation with sufficient capability will be too high.	Development	High
5	If the aerothermodynamics of the target body are not well understood/modeled, then heat shield performance will be compromised.	Mission	High
6	If the aerothermodynamics of the target body are not well understood/modeled, then the control actuators may not have sufficient control authority to maintain the flight path angle and the lift vector orientation.	Mission	Medium
7	If the entry heating (integrated heat flux and soak-back) cannot be accommodated, then components may overheat resulting in failures.	Mission	Medium
8	If autonomous optical navigation cannot correctly correlate the atmosphere altitude to the planet barycenter, then the density will not be as expected and may exceed the ability of the spacecraft to compensate.	Mission	Low



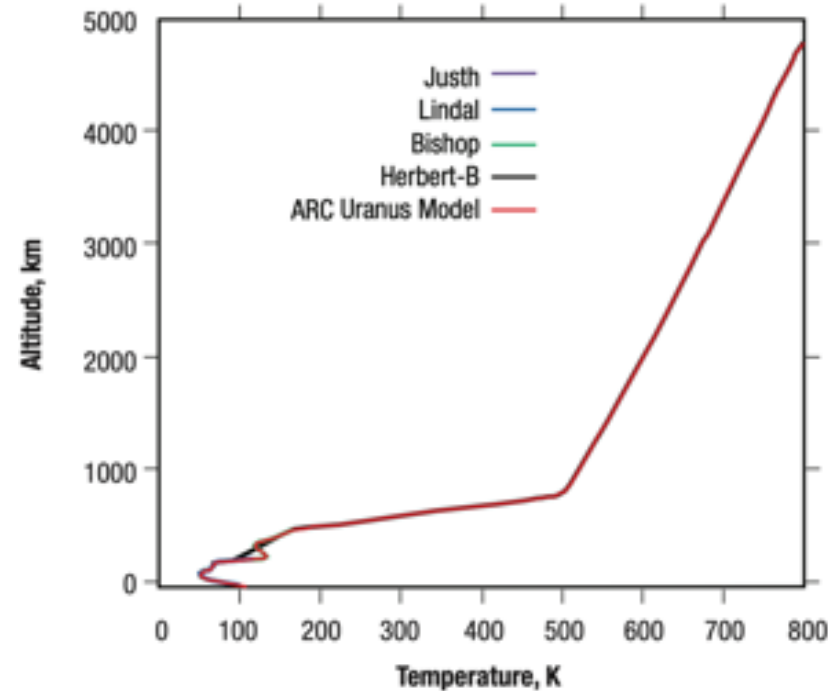
Credit: ADRAT Report

What architecture and requirements are necessary for tech demo?

- Improved atmospheric model fidelity informed by new data or reassessment of existing data
- Aerothermal response modeling including TPS surface and flow-field chemistry, and coupled TPS material response modeling
- TPS development of rigid body (e.g., HEEET) and 3D woven (e.g., ADEPT) structure, depending on mission implementation (e.g., higher heating rates, larger structure, integrated system)
- Control actuator development and performance assessment
- TRL advancement of Numerical Predictor-Corrector (NPC) algorithms for this application
- Density estimation algorithms for control and/or jettison timing
- Verification is needed that these algorithms can be supported by current platforms (e.g., for C&DH computational resources and timing, sensor accuracy and noise)
- Autonomous Optical Navigation (AutoNav) for a gaseous planet is needed for targeting of outer planets to compensate for poor ephemeris

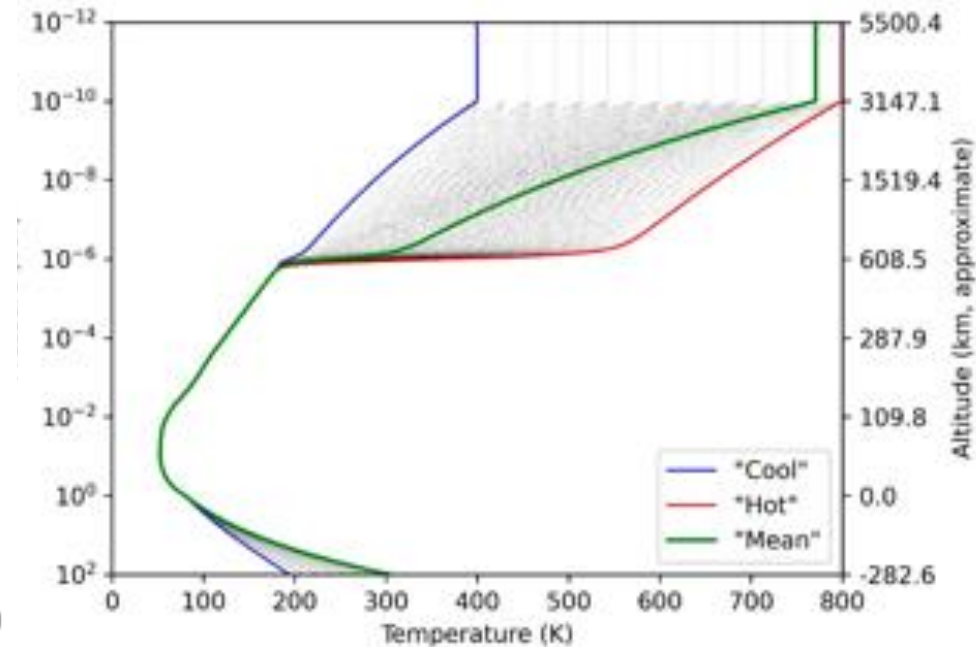
Atmospheric Uncertainties

- Atmospheric datasets from recent reanalysis of Voyager 2 data, data from Spitzer Space Telescope, comparison
- Comparisons with recent data from James Webb Space Telescope
- Aerocapture simulations (high-fidelity simulations similar to what is done on EDL flight missions) show 99%+ capture success rate



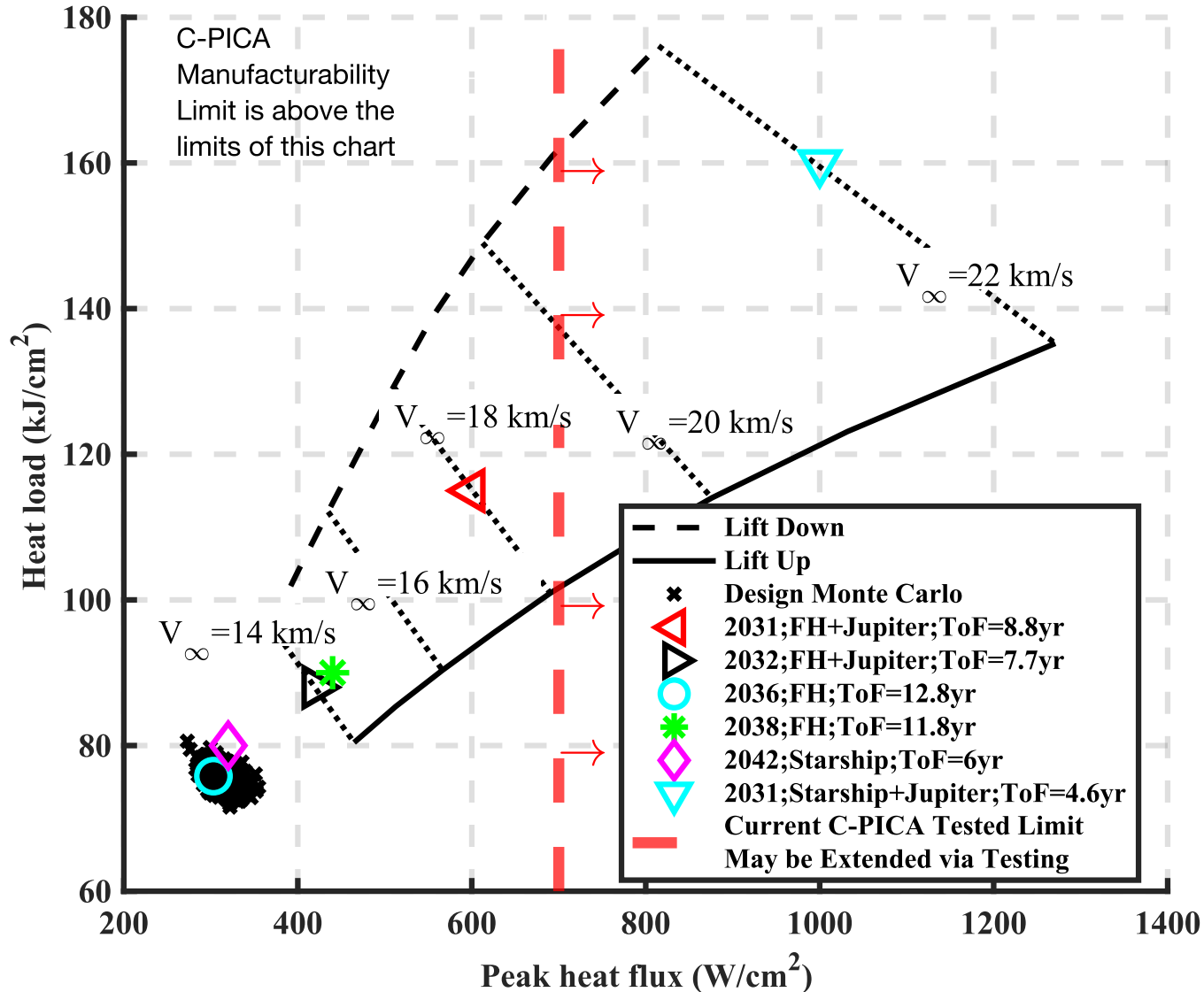
Uranus GRAM (pre-2024)

Credit: Uranus GRAM 2021



Uranus GRAM (2024+)

Aerosciences and Thermal Protection System Solutions

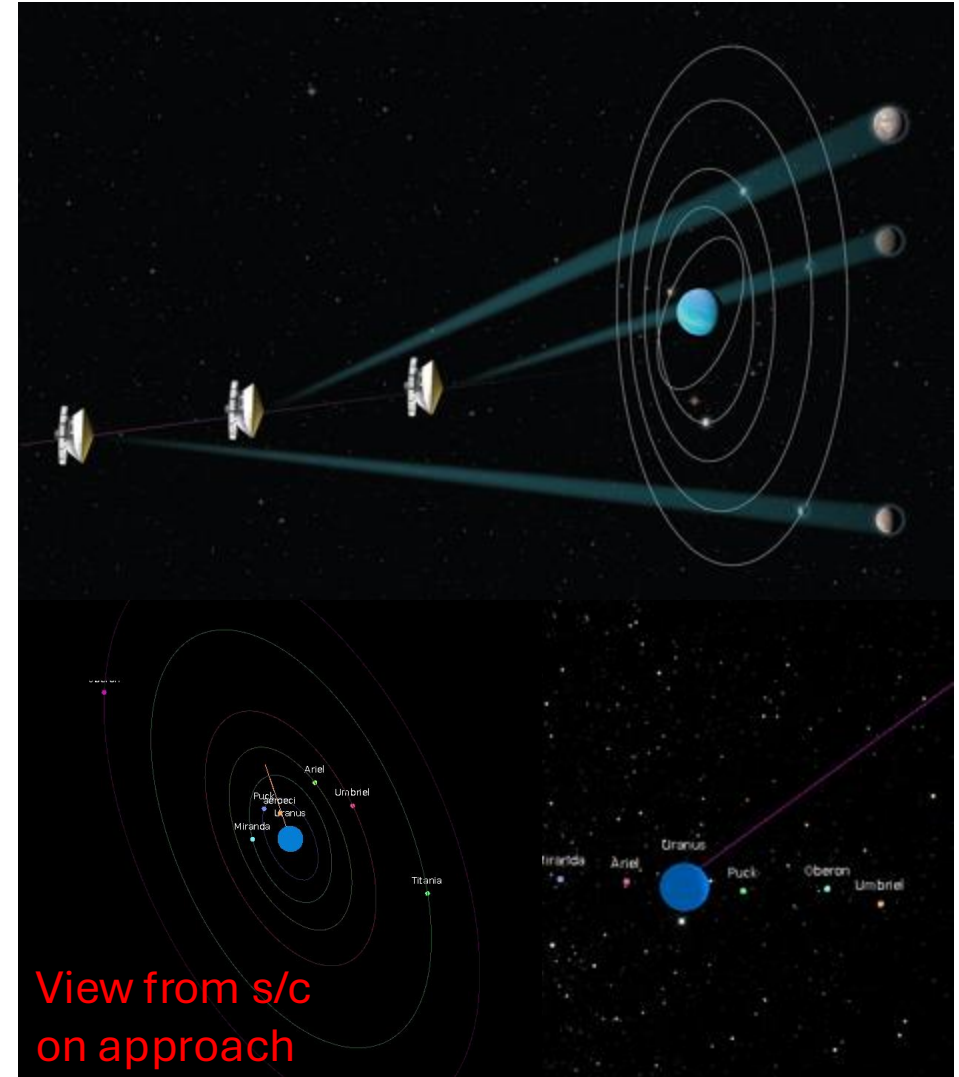


- ECI project developing computational capabilities for Giant planet missions
 - No atmospheric missions since Galileo mission to Jupiter (launched in 1989)
 - Lessons learned from other ECIs
- Aerocapture has much lower maximum heating conditions than direct entry probes
 - Radiative heating insignificant for most conditions
- Conformal PICA – lightweight solution available for Thermal Protection System



Navigation Solution

- OpNAV Approach Campaign
 - Uranus is a challenging OpNAV target
 - Fills spacecraft camera (LORRI) field of view ~8 days from entry
 - No features to register and planetary atmospheres are known to introduce errors to limb-scanning
 - Plan is to use Uranus satellites as beacons to indirectly observe correlated to Uranus position
- Analysis shows no need for AutoNAV
 - Ground-in-the-loop (even with 8 hours one-way light speed) produces desired entry accuracy



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Aerocapture Demonstration at Earth

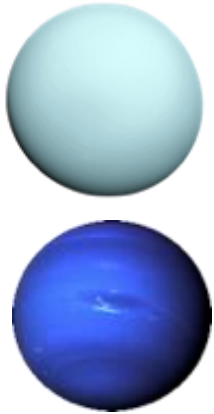


- Earth demo would not directly address the outer planet aerocapture risks, which are dominated by the uncertainty of the target environment
 - Can't meet the high heat fluxes or entry velocities
- Could improve the integrated system TRL for aerocapture methods of Lift Modulated Direct Force Modulation or Drag Modulation
- Valuable data for model correlation: TRL advancement and model correlations would provide substantial benefit to destinations with a well-understood atmosphere and approach velocities similar to the demonstration velocity
- Demonstration include drag tab control algorithms and mechanisms, heating rate modeling, center-of-gravity (cg) change control algorithms and mechanisms, packaging, mechanisms, and jettison timing control algorithms
- Instrumentation (thermocouples and heating rates) and post-flight analysis, CFD and TPS model correlation would improve scaling approaches
- Scaling from a SmallSat to the larger interplanetary spacecraft is an important consideration.
- Laminar-to-turbulent flow regimes could be addressed
- Data needed to address the overall aerocapture technology development and the specifics for that demonstration,

Aerocapture Technology Demonstration Traceability to Ice Giants Mission



How can Aerocapture enable Ice Giants Missions?



Typical Fully-Propulsive Mission

- Fast interplanetary speeds for outer planets
- **Need 50% or more mass** for fully-propulsive orbit insertion (requires ΔV of 1-2 km/s)
- Typical mission **require long cruise phase** (13-17 years)

Aerocapture Enabled Mission

- Reduced propellant need; **increase on-orbit mass by 40%**
- Aerocapture less sensitive to faster interplanetary trajectories – **reduce trip time by 3-5 years**
- Savings used for launch vehicle choice or increased on-orbit science payload
- Fit a larger cap mission into smaller cap. e.g., **Flagship class mission in New Frontiers cap**

Steps for Aerocapture at the Ice Giants

Requirements	Demonstration
Hypersonic guidance for target orbit	Demonstrated on Mars (MSL/Mars2020) and Earth (EFT-1, Artemis 1). Relevant demonstration with Earth Technology Demonstration Mission (TDM).
Thermal Protection System for Ice Giants (IG)	TPS (PICA) demonstrated on Mars/Earth or selected (3MDCP) for current missions like MSR EEV. Will be used on Earth TDM but not at IG conditions.
Autonomous periapsis raise maneuver	Will be demonstrated with Earth TDM
Control systems demonstration	Earth TDM could demonstrate relevant control systems using trim tabs or RCS engines. Design of the Ice Giants control would be similar.
Aeroshell separation after aerocapture	Could be demonstrated with Earth TDM
Target tight entry corridors (entry flight path angle) using AutoNAV and OpNav	Demonstrated on missions like Deep Space 1 (DS1)
Packaging science instrumentation, high gain antenna within aeroshell	Feasibility has been shown in mission studies for Ice Giants missions

Earth Demonstration from Geostationary Transfer Orbit (GTO)



- Piggy-back on geostationary transfer launch
- Demonstrates direct force control and on-board guidance ($\Delta V \sim 2$ km/s)
- High energetic entry – demonstrates heating objectives
- Total mission time ~ 30 hours (from separation at GTO apoapsis to end of mission)

