Design Considerations for Aerocapture Delivery of Uranus Orbiter and Probe

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GNC-23/AFM-16: Entry, Descent, and Landing Technology – Aerocapture for Ice Giants I
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NASA Early Career Initiative

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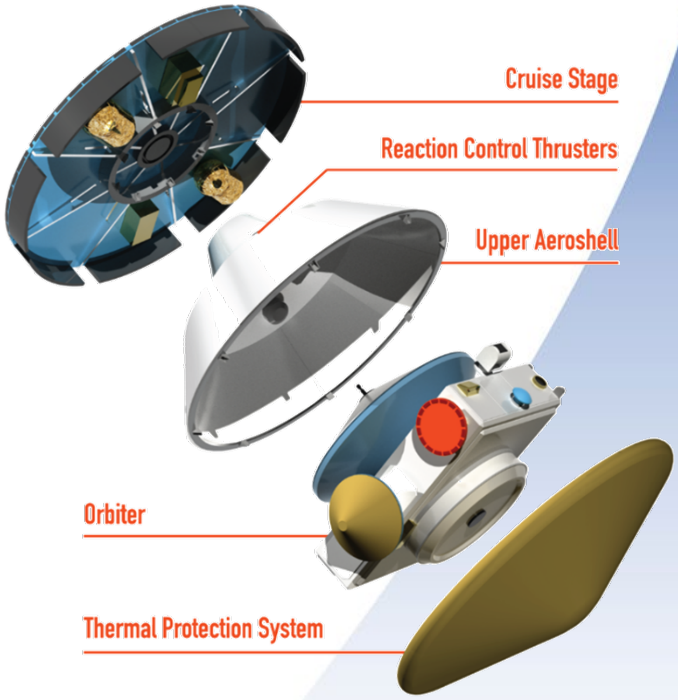
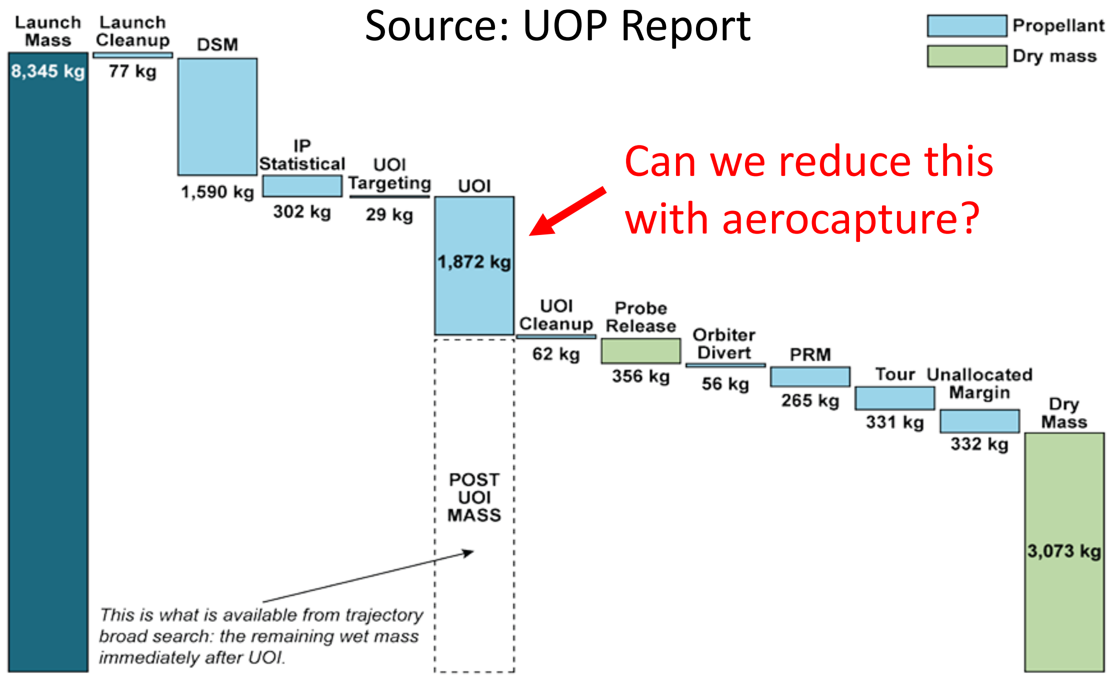


Motivation

- Aerocapture can potentially enable faster arrival trajectories and reduce orbit insertion propellant mass at Uranus
- Question: Can we design the aeroshell to accommodate the orbiter and probe?



Uranus Aerocapture Talks SciTech 2025

- ECI Overview (Dutta) — AIAA-2025-?
- Mission Design and Navigation (Mages) — AIAA-2025-?
- 6DoF (Deshmukh) — AIAA-2025-?
- Aerothermal (Scoggins) — AIAA-2025-?
- Aerodynamics (Shellabarger) — AIAA-2025-?
- Thermal Protection System (Morgan) — AIAA-2025-?
- Mechanical (Gomez-Delrio) — AIAA-2025-?
- Guidance (Matz) — AIAA-2025-?
- Navigation (Chadalavada) — AIAA-2025-?

NASA Space Technology Mission Directorate funded Early Career Initiative (ECI). Project aims to mature the analysis and technology state of Uranus aerocapture

Outline

- **Motivation**
- **Aeroshell Packaging**
- **Thermal Design and Analysis**
- **Cruise Stage**
- **Mass Properties**
- **System Trades**
- **Summary**

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LaRC: NASA Langley Research Center

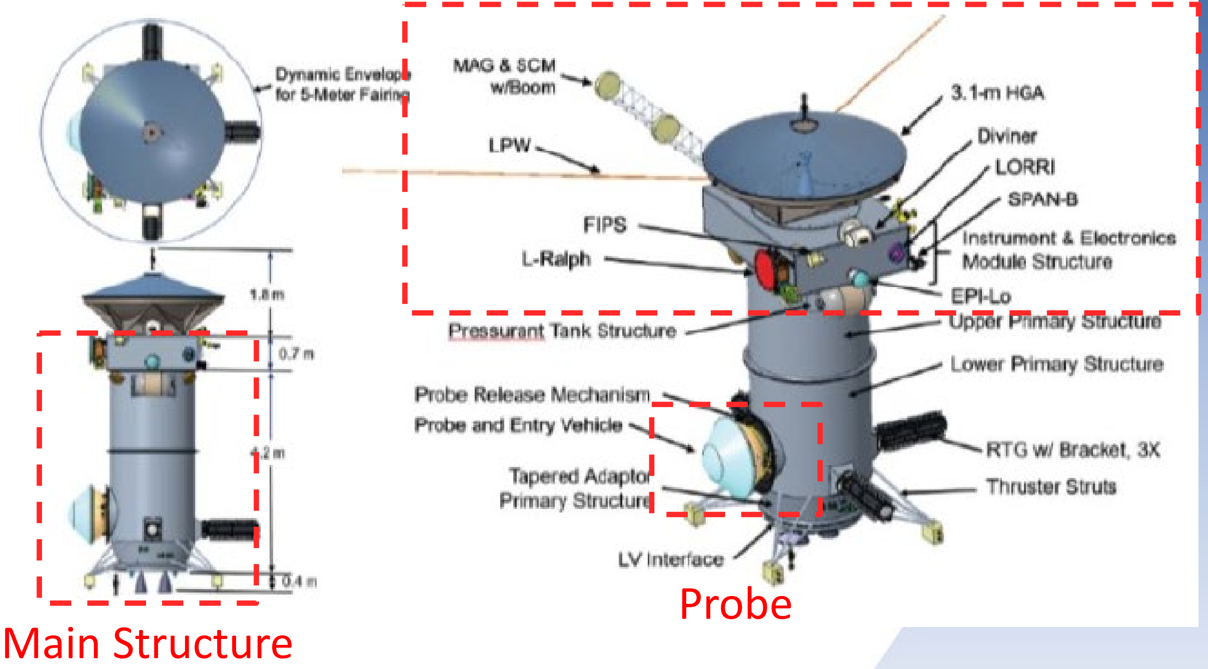
Uranus Orbiter and Probe Design

Orbiter
- 1932 kg bus
- 60 kg instrument payload
- 3.1m High Gain Antenna

Atmospheric Probe
- 233 kg entry mass
- 1.25m diameter

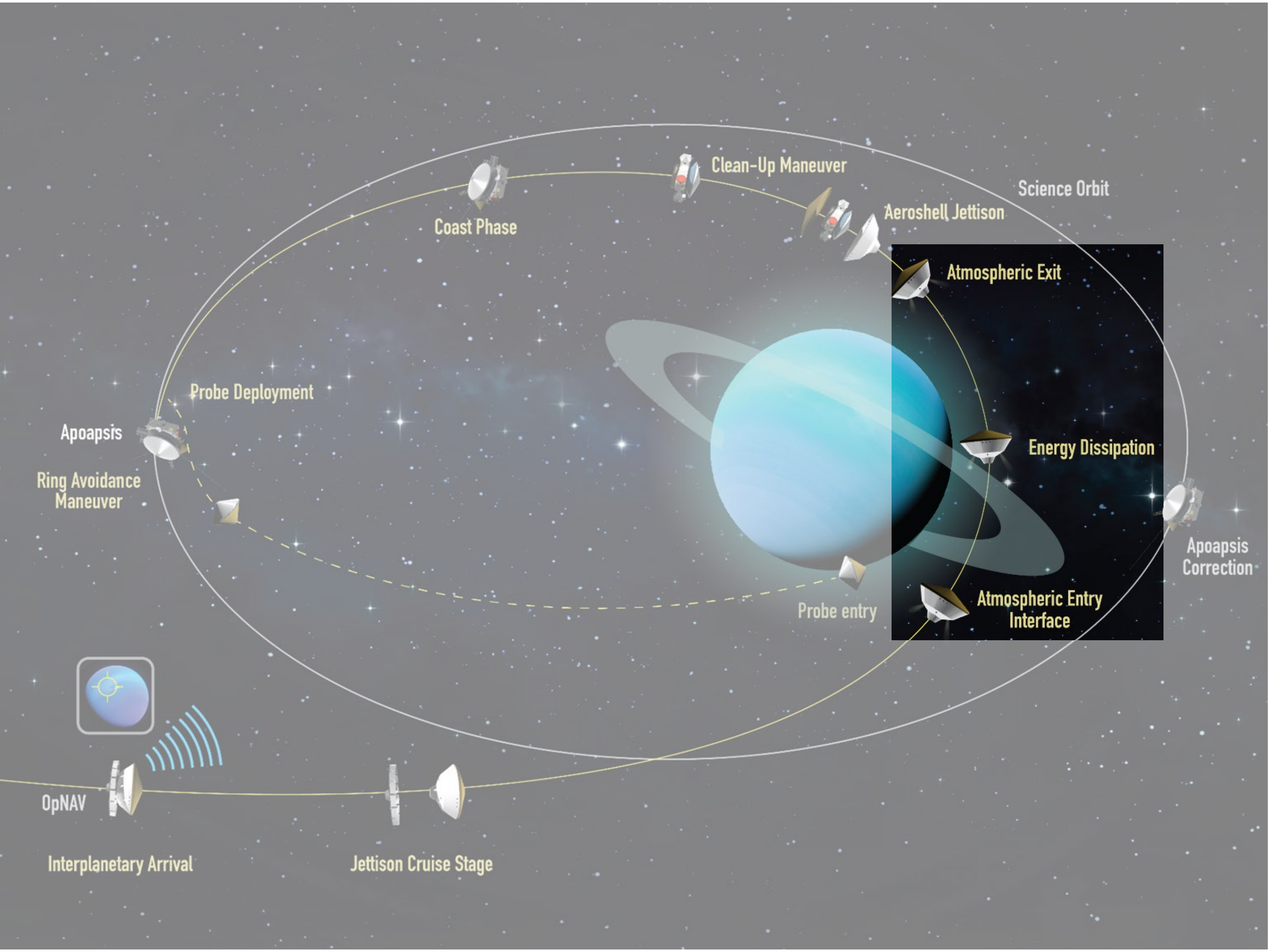
Main structure
- Propellant Tanks store ~4400 kg of bi-propellant
- 3 Next-Gen Radioisotope Thermoelectric Generators

Uranus Orbit Insertion (UOI) Burn
- 1.011 km/s -> **1872 kg propellant needed**
- **Propellant constitutes 28% of Pre-UOI mass**



Source: UOP Report

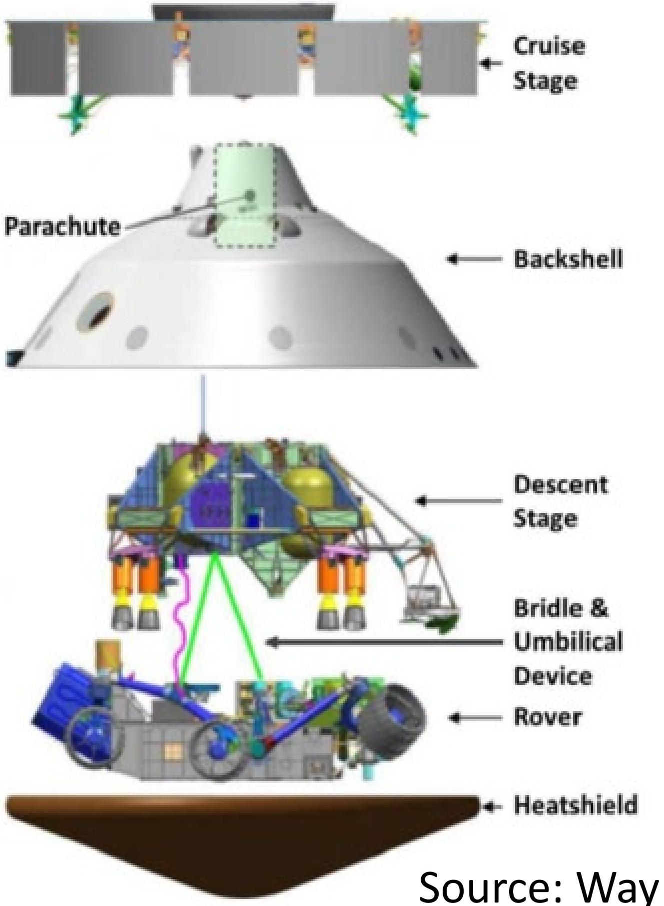
Aerocapture for Uranus Orbit Insertion



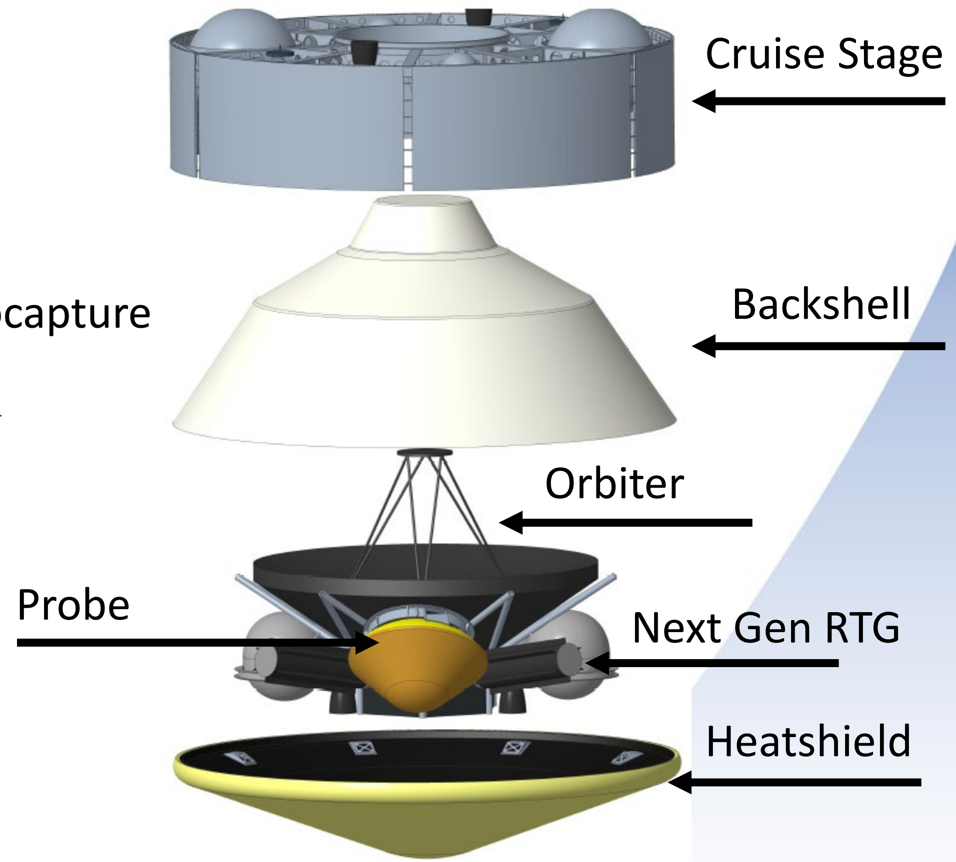
- **Aerocapture can reduce mass and transit time**
- **Use Uranus atmosphere to achieve UOI ΔV**
  - Goal: Reduce propellant mass
  - Trade: Aeroshell mass
- **Q: Can the same the same orbiter and probe be:**
  - Volumetrically packaged in aeroshell?
  - Mechanically integrated in aeroshell?
  - Delivered to the same science orbit while achieving reduction in overall mass?

Aeroshell Design and Packaging

- **Utilizing MSL-derived aeroshell architecture**
  - Scale aeroshell by diameter to 4.57m
  - Conformal PICA Thermal Protection System



MSL → Aerocapture UOP

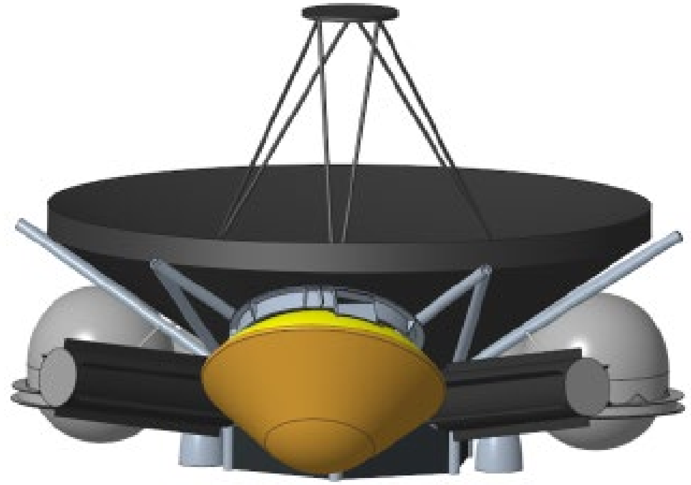


Source: Way et al.,

Aeroshell Payload Components

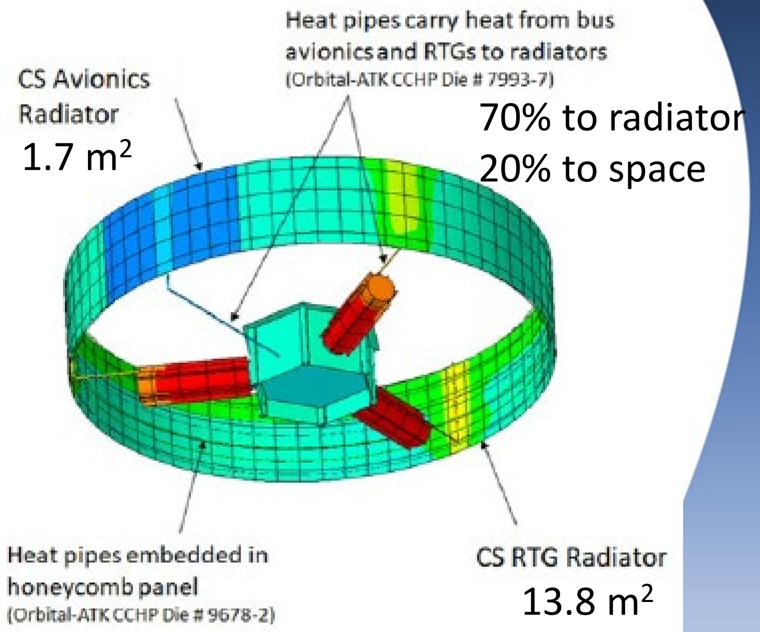
- Utilize UOP Master Equipment List to obtain orbiter and probe payload
- Packaging done to keep c.g. close to aeroshell nose (aerodynamic stability) and offset centerline (trim L/D)
- Central aluminum truss for proper distribution of structural loads and honeycomb closeout panel for bus components

Component/Subsystem	Notes
Uranus Probe	Heatshield and Descent Module
Instrument Payload	Magnetometers, IR cameras, LORRI
RF communications	3.1 meter HGA
Avionics	-
Electrical Power	RTGs, batteries
Propulsion systems	Engines, piping, valves, supports
Structures	RTG brackets, thruster supports
Attitude Determination and Control	-
Thermal Control	MLI, heaters, louvers
Harness	-



Thermal Design and Analysis

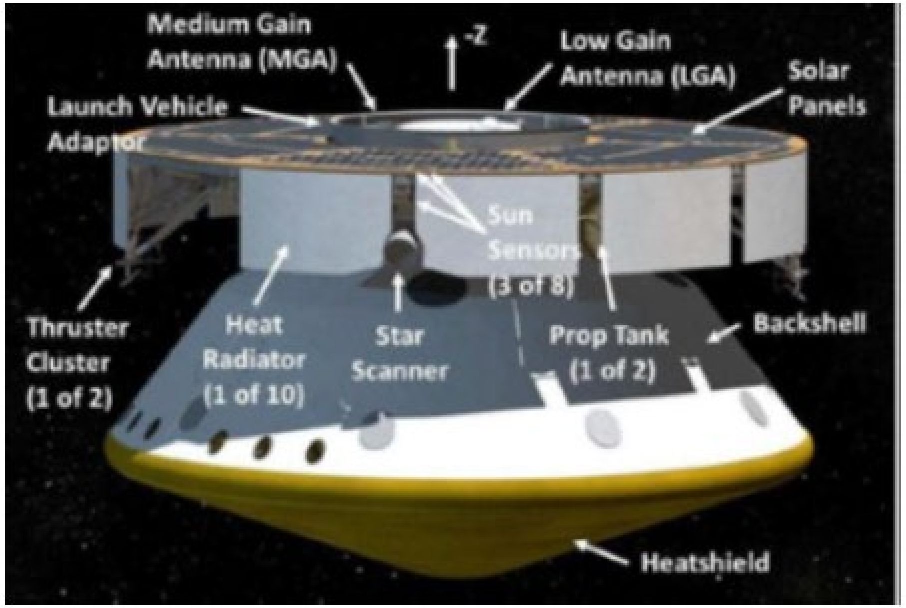
- **Potential concerns for thermal management**
  - RTGs produce ~11.3 kW waste heat
  - Cruise stage separation removes primary heat rejection capability
- **Passive thermal management**
  - Heat pipes to conduct waste heat to cruise stage radiators
  - Multi-Layer Insulation with Kapton used to minimize radiative heat loss (ex. bus avionics)
  - High emissivity coatings applied on external surfaces for radiative heat transfer (ex. Heatshield interior)
- **Assessed thermal analysis cases**
  - Critical components are within thermal limits
  - Transient analysis indicates cruise-stage jettison should occur no more than 30 min before entry



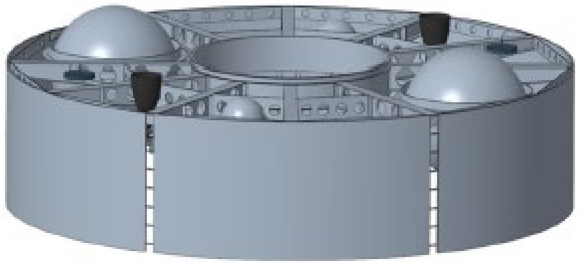
Mission phase	Hot or cold case?	Bus heat (W)	RTG Heat (W)	MLI e^*
Near-earth commissioning	Hot	310.5	3755	0.030
Venus flyby	Hot	171.0	3755	0.030
Hibernation cruise at 2AU	Cold	157.0	3755	0.030
Near Uranus	Hot	263.7	3755	0.015
Near Uranus	Cold	263.7	3755	0.030
Cruise stage jettison	Hot	263.7	3755	0.015
Aerocapture	Hot	263.7	3755	0.015

Aerocapture Cruise Stage

- **Similar design as MSL but some modifications**
  - Removed solar panels
  - Orbiter provides GNC capability
- **Design**
  - Creo assessment of aluminum structure with 6 g launch loads
  - Two bi-propellant engines for deep space maneuvers
  - Radiators with heat pipes



Source: Mur et al.,



Subsystem	Mass (kg)
Propulsions	243
Heat Rejection System	177
Structures	280
Aeroshell seperation fittings	55
Communications	11
Total dry mass	766

Aeroshell Mass Properties

- Current Best Estimate: From UOP and MSL reported masses and CAD model results
- Max Growth Allowance used to obtain Maximum Expected Values
- Fixed Maximum Permissible Value used by project as calculated using standard AIAA mass control approach

Aerocapture Propellant Mass Breakdown

Mission phase	Maneuever	ΔV (m/s)	ζ	Propellant mass, kg
Interplanetary trajectory	DSM	650	1.2317	1061.6
Aerocapture	Atmospheric flight	-	1.0141	50.0
	PRM	144.0	1.0473	101.8
	ACM	49.0	1.0158	33.6
Operational	Probe release	46.4	1.0150	31.3
	Moon tour	289.3	1.0972	161.3
	Margin	319.9	1.1080	161.8

Aerocapture
UOI = 185 kg

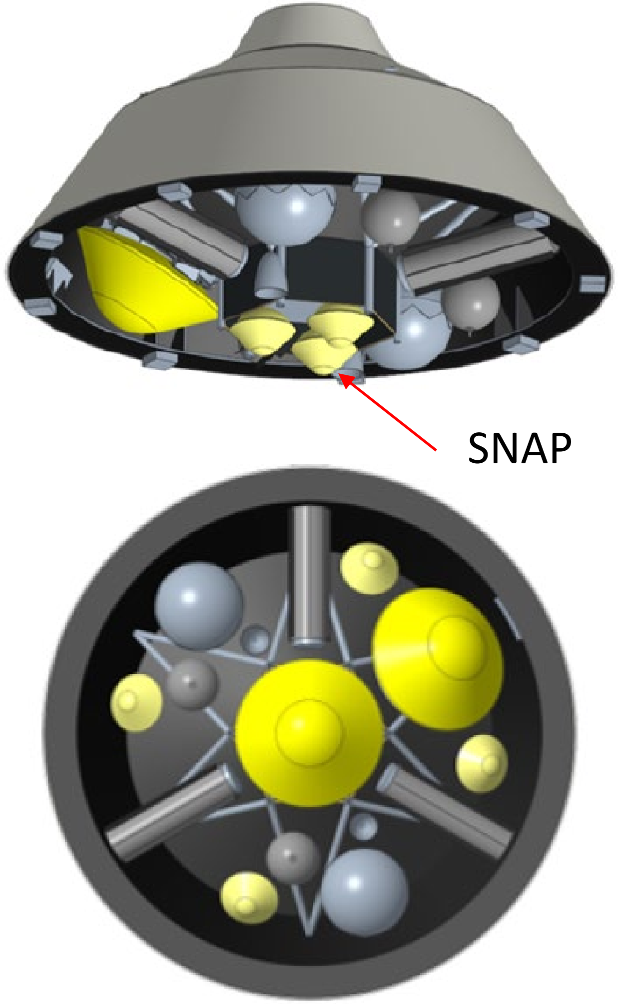
UOP
UOI = 1872 kg

Aerocapture Mass Breakdown

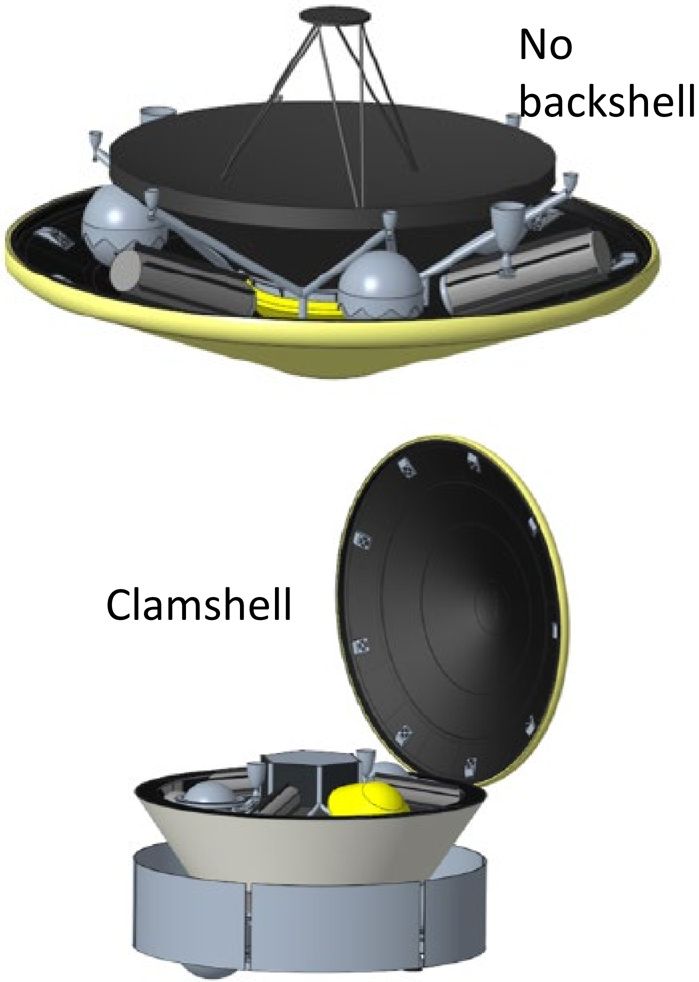
	CBE, kg	MEV, kg	Total MGA, %	MPV, kg	Margin, %
Aerocapture dry system (Aeroshell + payload)	2620	3061	16.9%	3524	17.7 %
Propellant	540	-	-	-	-
Total wet mass	3159.6	3601	14.0%	4064	14.6%

Potential System Trades*

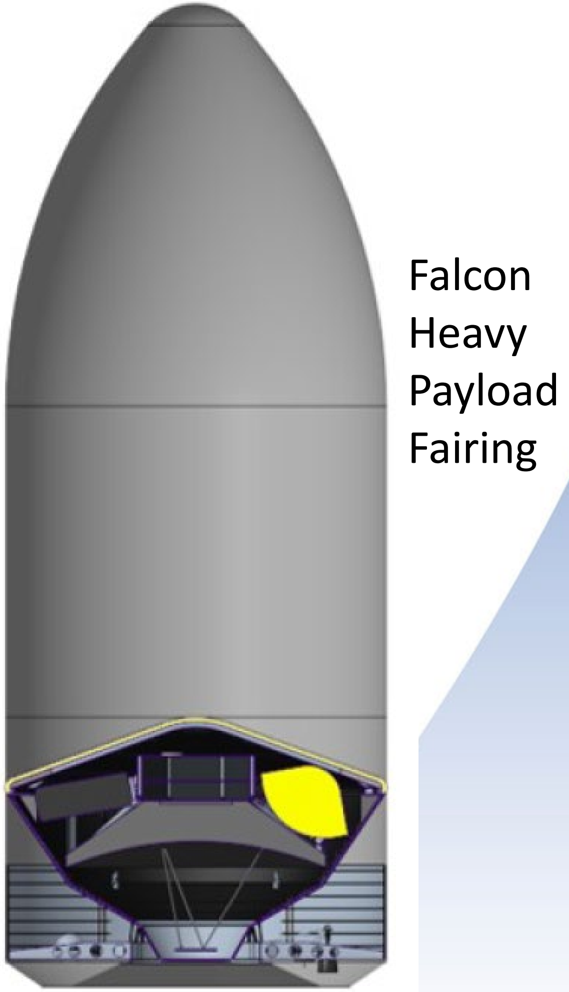
➢ Multiprobes



➢ Aeroshell Configs



➢ Launch Configs



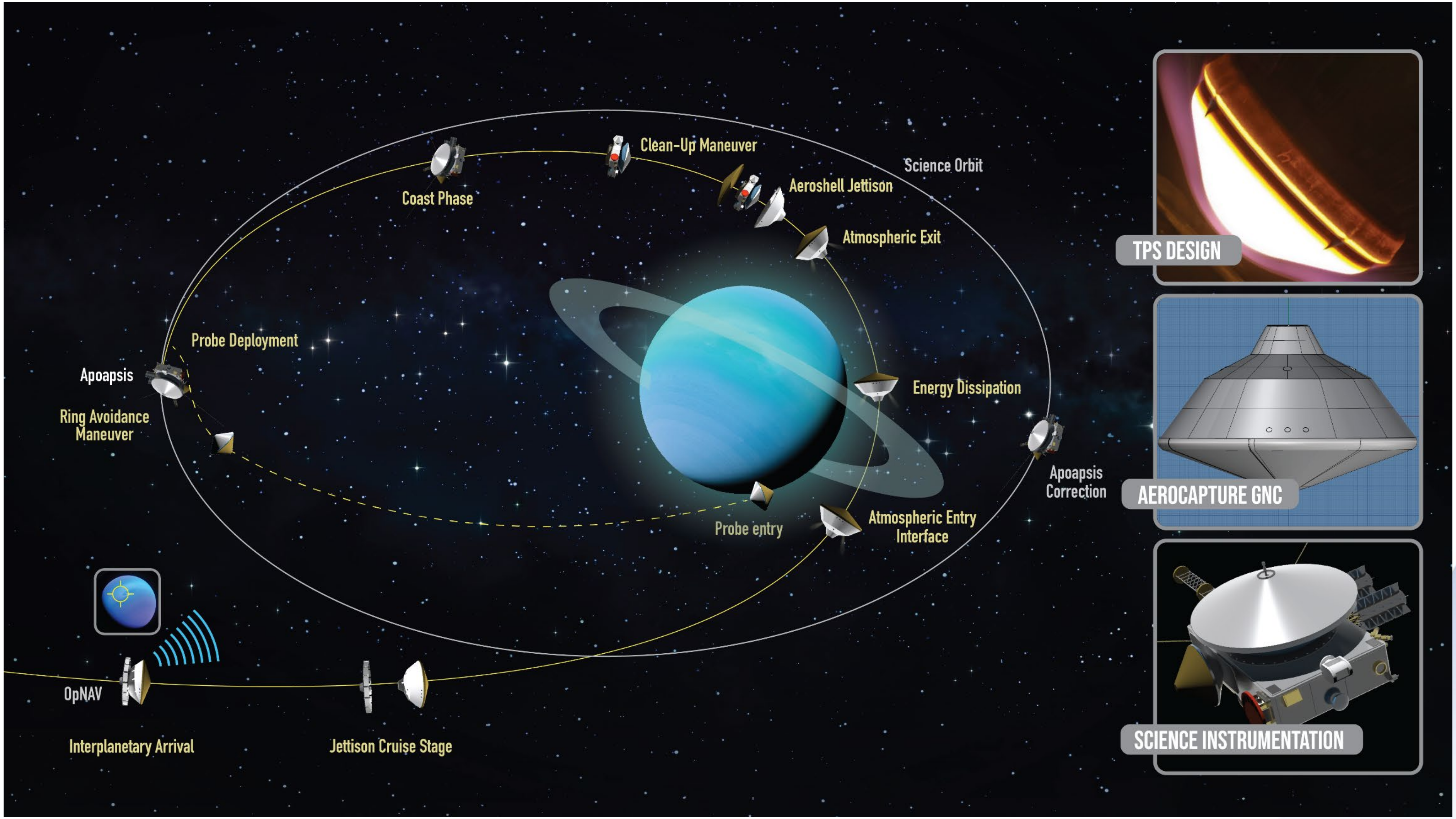
*These are conceptual ideas. Further analysis is needed on each potential system trades

Summary

- Developed packaging scheme and mass estimate for encapsulating UOP in MSL-derived aeroshell
- Developed cruise stage capable of providing propulsive, communications, and heat rejection capability for aerocapture vehicle in transit to Uranus
- Thermal analysis indicate passive heat rejection system is sufficient to solving thermal challenges associated with Next Gen-RTG waste heat
- Mass properties indicate sufficient margin for early conceptual design
- Aerocapture has potential to save significant amount of mass as compared to full-propulsive mission concept

We can design an aeroshell to house Uranus orbiter and probe

Questions


Clean-Up Maneuver
Science Orbit
Coast Phase
Aeroshell Jettison
Atmospheric Exit
Probe Deployment
Apoapsis
Ring Avoidance Maneuver
Energy Dissipation
Apoapsis Correction
Probe entry
Atmospheric Entry Interface
OpNAV
Interplanetary Arrival
Jettison Cruise Stage
TPS DESIGN
AEROCAPTURE GNC
SCIENCE INSTRUMENTATION

Backup

Aerocapture vs Fully Propulsive Design Comparison

- **Add mass breakdown comparison for aerocapture (including cruise stage + aeroshell)**

	UOP	UOP aerocapture	Aerocapture mass savings
Launch MEV mass, wet	6662 kg	5625 kg	1003 kg
Total propellant at launch	4368 kg	1601 kg	2767 kg