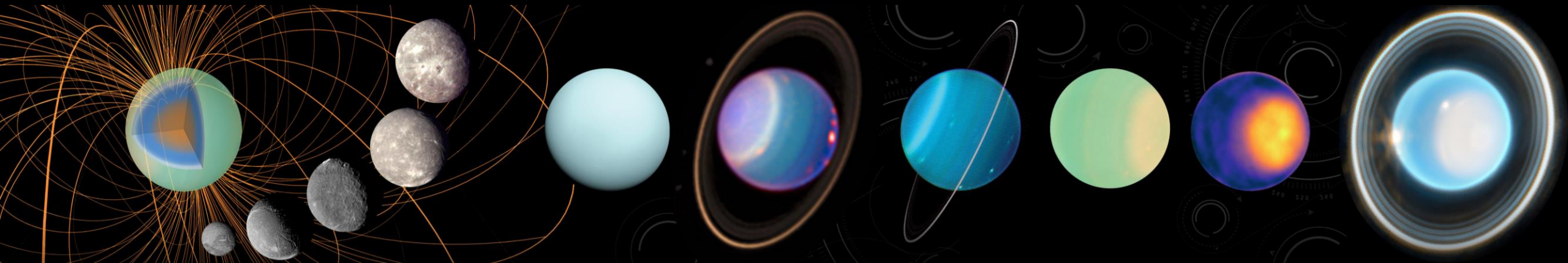


Uranus Orbiter Probe Drivers and Trades

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Uranus Atmosphere

- Uranus' atmosphere is mostly hydrogen and helium, with a small amount of methane and traces of water and ammonia
 - Uranus' planetary atmosphere, with a minimum temperature of 49K (-224.2 degrees Celsius).
 - Wind speeds can reach up to 560 miles per hour (900 kilometers per hour).
 - Winds are retrograde at the equator, blowing in the reverse direction of the planet's rotation, closer to the poles, winds shift to a prograde direction, flowing with Uranus' rotation.
- The Uranus atmosphere composition and interior structure are known much less well than those of the gas giants Jupiter and Saturn.
- Key questions regarding Uranus's growth rate and formation location also remain unsolved. Measurements of the concentrations of CO in the troposphere, plus noble gases, are needed to determine whether Uranus is a volatile-rich ice giant or a rock-dominated super- Earth. ¹
- Variation of composition with depth provides information not only on how the planet formed, but also how it has evolved since formation and about its current interior structure.

The UOP Probe Drivers

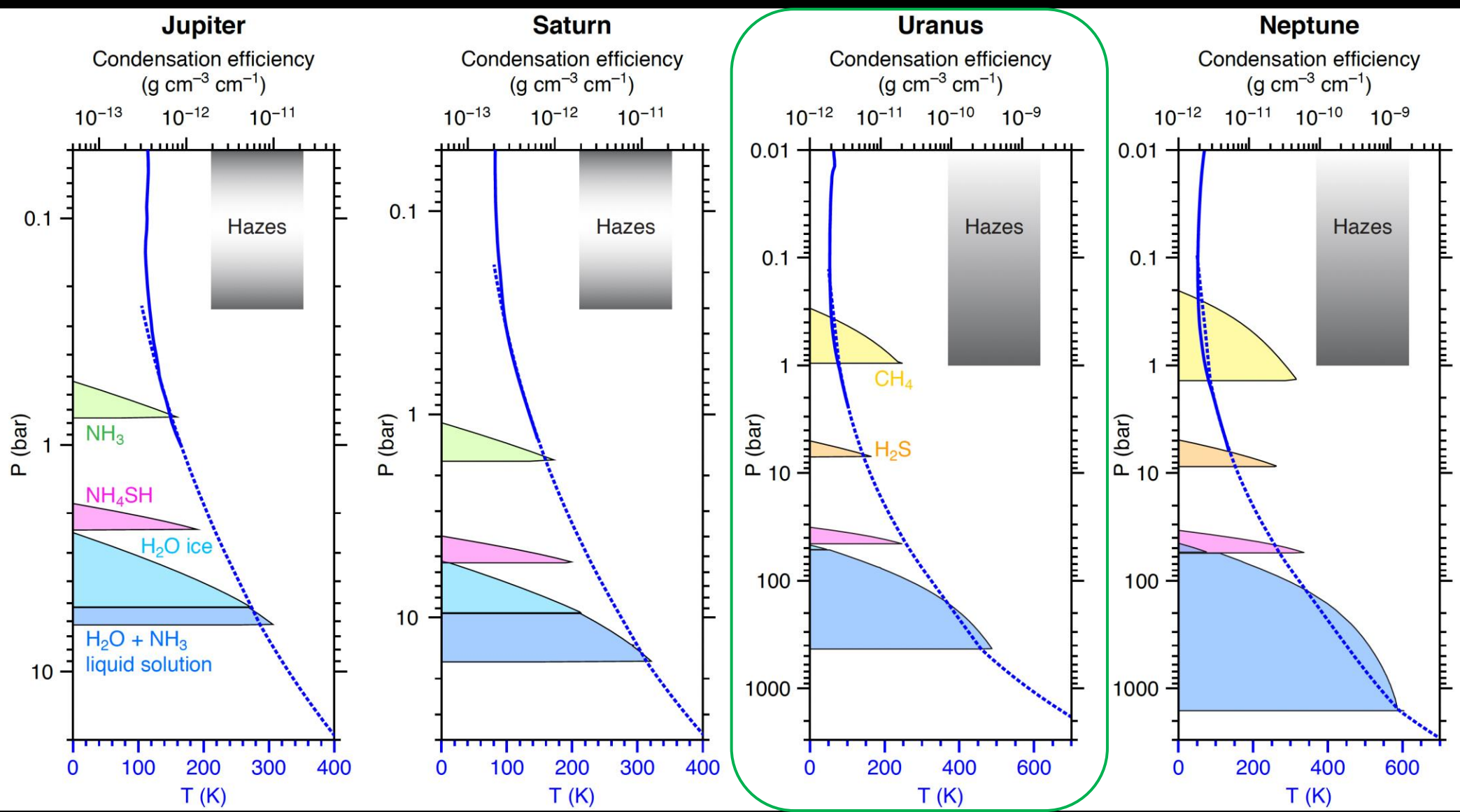
- The Uranus Orbiter Probe (UOP) probe is required to make in situ measurements of ice-to-gas ratios and absolute abundance of species such as noble gases and water, to answer core questions about the conditions in the planetary nebula and the planet formation process.

	Science Objective	Measurement	Nominal Instrument	Mission Functional Requirement
Atmospheres	A1. How does atmospheric circulation function, from interior to thermosphere, in an ice giant?	A. Cloud top zonal and 2D winds, waves to ~10 m/s resolution	NAC, imaging at 50 km/pixel	Repeated views of same features over timescales of minutes to hours
		B. <i>In situ</i> vertical wind profile to 10–20 m/s resolution	USO (probe), 10 measurements per scale height	Probe to 5 bars
		C. Resolved composition, disequilibrium species mapping (to $P < 3$ bars): CH_4 , H_2S , H_3^+ , C_2H_2 , C_2H_6 , etc., hydrogen ortho/para fraction to mixing ratio $\pm 20\%$	Vis/NIR, 1000 km/pixel	
			TIR, ~1000 km horizontal spatial resolution	
			MS (probe)	Probe to 5 bars, 10 bars preferred
	A2. What is the 3D atmospheric structure in the weather layer?	Ortho/para sensor (probe)		Probe to 5 bars
		D. Depth of atmospheric winds (gravity moments)	Radio Science, gravity passes	Polar and equatorial passes, distances of $1.1 R_u$
		A. Cloud tomography and aerosols	Vis/NIR imaging spectra at 500–1000 km/pixel	Repeated views of same features over timescales of hours
			WAC or NAC imaging at 500–1000 km/pixel	Repeated views of same features over minutes to hours
		B. Vertical temperature profile to $\pm 1\text{K}$	ASI (probe), 4 measurements per scale height	Probe to 5 bars
			Ortho/para sensor (probe)	Probe to 5 bars
			Radio Sci + UltraStable Oscillator, occultations	Atmospheric occultations
	A3/I1. When, where, and how did Uranus form, and how did it evolve both thermally and spatially, including migration?	C. Global temperature variations in troposphere, stratosphere, thermosphere	TIR, 500-1000 km/px mapping	Global coverage, repeated views
		A. Noble gas (& isotopes of He, Xe) abundances to $\pm 5\%$	Vis/NIR spectra at 500–1000 km/pixel	
			MS (probe)	Probe to 5 bars
		B. Elemental (& isotopes of H, C, S, N & O (stretch goal)) abundances, lower bounds on CH_4 , H_2S , NH_3 , H_2O , and the variation with depth	MS (probe)	Probe to 5 bars, 10 bars preferred
		C. Global distribution of atmospheric composition	Same as A1.C above	
		D. Global energy balance (Bond albedo and thermal emission) to 1%	TIR, 1000 km/pixel	Repeat orbiter ~yearly to determine variability
			Vis/NIR spectra at 500-1000 km/pixel	Repeat ~yearly to determine variability

The UOP Probe Drivers Trades

- Uranus atmosphere at probe entry and depths
 - Depth requirement
 - Starting and end temps and pressures
 - Basic science goals of the probe system
 - Probe release and entry timeline (RHU vs heaters; comm geometry; probe power)
 - Instrument accommodation (SWaP, and return data-volume)
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- Optimize post-capture Probe deployment approach from 2021 Decadal
 - Balance Probe coast (release to entry) duration and required Δv for Orbiter divert
 - Minimize Probe entry acceleration loads and peak heating
 - Provide safe ring traverse for Orbiter and line of sight through entry and descent
 - Provide robust Probe data uplink; maximize likelihood of successful data return

Uranus Atmosphere Conditions and Probe Environment



UOP Probe: Early Design Approach

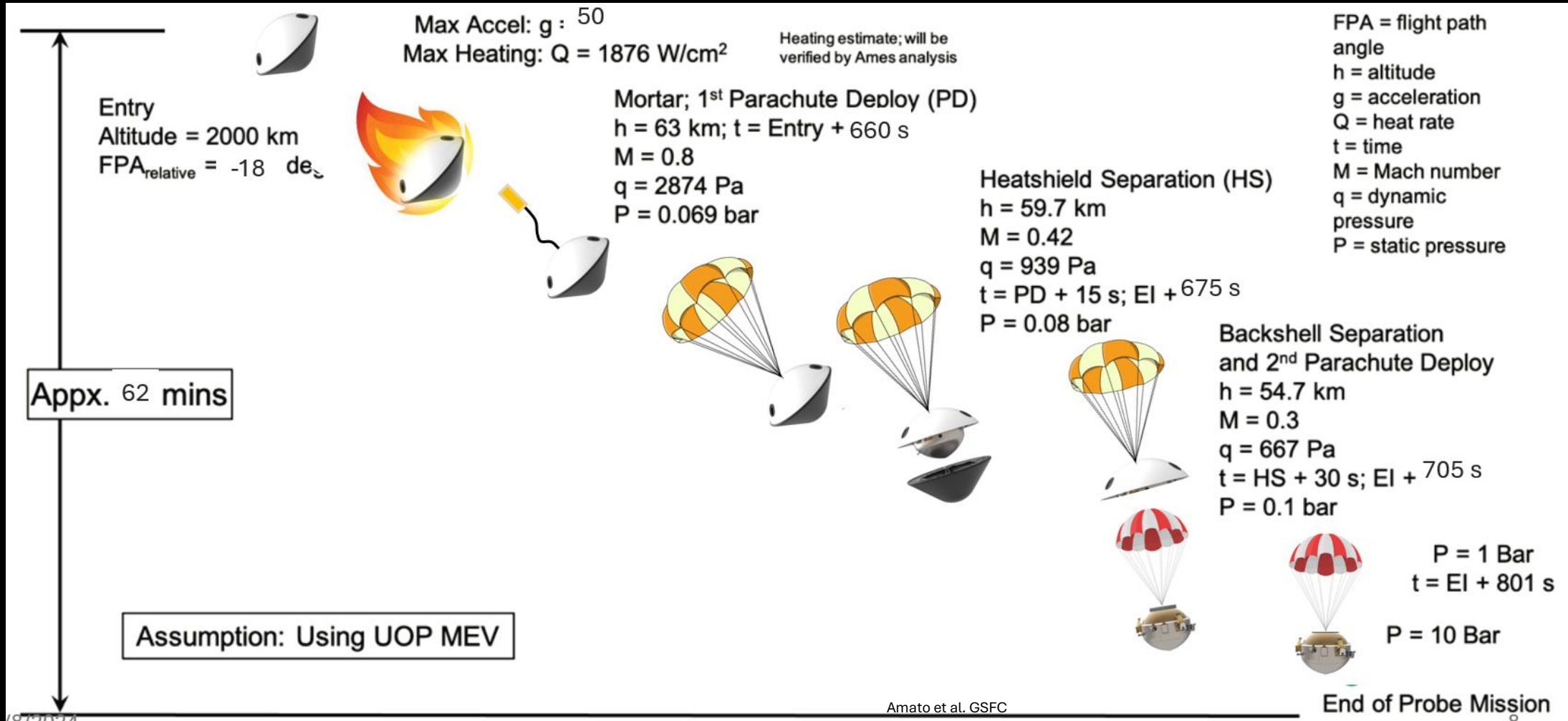
- Entry System (ES)
 - Shape/Heritage based on Pioneer Venus, Galileo
 - RHUs mounted within ES for coast thermal (similar to Galileo)
 - ESI sensors included in design
 - 1st Parachute (ES chute) conical ribbon
 - 2nd Parachute (descent chute) ringsail
- Descent Vehicle (DV)
 - Single string with select redundancy for probe
 - Adaptive Data Rate (ADR) during descent relay using Frontier Lite Radio
 - UHF for relay communications with orbiter
 - Hibernation mode during coast
 - Total Data Volume during descent is 37 Mbytes
- Orbiter to Probe Interface
 - Spin-Separation mechanism spins/release probe vehicle (Spin-Sep captured in orbiter MEL)

Probe Release	
Probe Release (from orbiter)	< 30 days from AEI
Spin, Spin Rate	Passive ~3-5 rpm (Spin-SEP mechanism)
Entry Conditions	
Entry Altitude (AEI)	2000 km
Flight Path Angle (FPA)	-18°
Max Acceleration	~ 50g
Descent Conditions	
Target Depth	10 bar
Margined Design Depth	12 bar
Time from Entry to Target Depth	~60 minutes (TBR)
Range to Orbiter	~43,000 to ~7,000 km (TBR)
Design Parameters	
Entry System Mass (CBE/MEV)	159 kg / 179 kg
Descent Vehicle Mass (CBE/MEV)	149 kg / 186 kg
Total Probe Mass (CBE / MEV)	338 kg / 402 kg
Total Probe MPV	483 kg

UOP Probe: Top Level ConOps

Phase/Event	Activities	Orbiter Resources
Cruise to Uranus system / Pre-Release Checkouts	- Occasional probe checkout using orbiter hardline interface (power and data) - Remaining time, probe is powered off	- Duration: ~ 1 hour for each checkout - Estimated Power: 50 W Average - Estimated Data Volume: ~6,500 kbits
Probe Release	- Pre-Release Configuration for Probe - Release Probe < 30 days before AEI	- Duration: ~1 hour - Estimated Power: 50 W Average - Estimated Data Volume: 4,300 kbits
Coast	Low power/Hibernation mode for ~30 days	None – No relay comm during coast
Entry	- Entry Duration from AEI: ~ 5 minutes - Transitions to subsonic, two parachutes deploy - Backshell/Heatshield Jettison - Begin Relay Link with ADR after backshell jettison - Probe avionics stores data for later transmission	None – No relay link until after backshell is jettison
Descent	- Descent/Science phase duration: ~55 minutes - Probe descends on Parachute #2 through 10 bar - ADR is operating with fixed step mode as backup	- UHF comm relay with ADR - Duration: ~1 hour - Estimated Data Volume: 37 Mbits - Orbiter tracks probe for TBD minutes (provide margin past 10 bar)

UOP Probe: Possible Entry and Descent



UOP Probe Instruments and Measurements

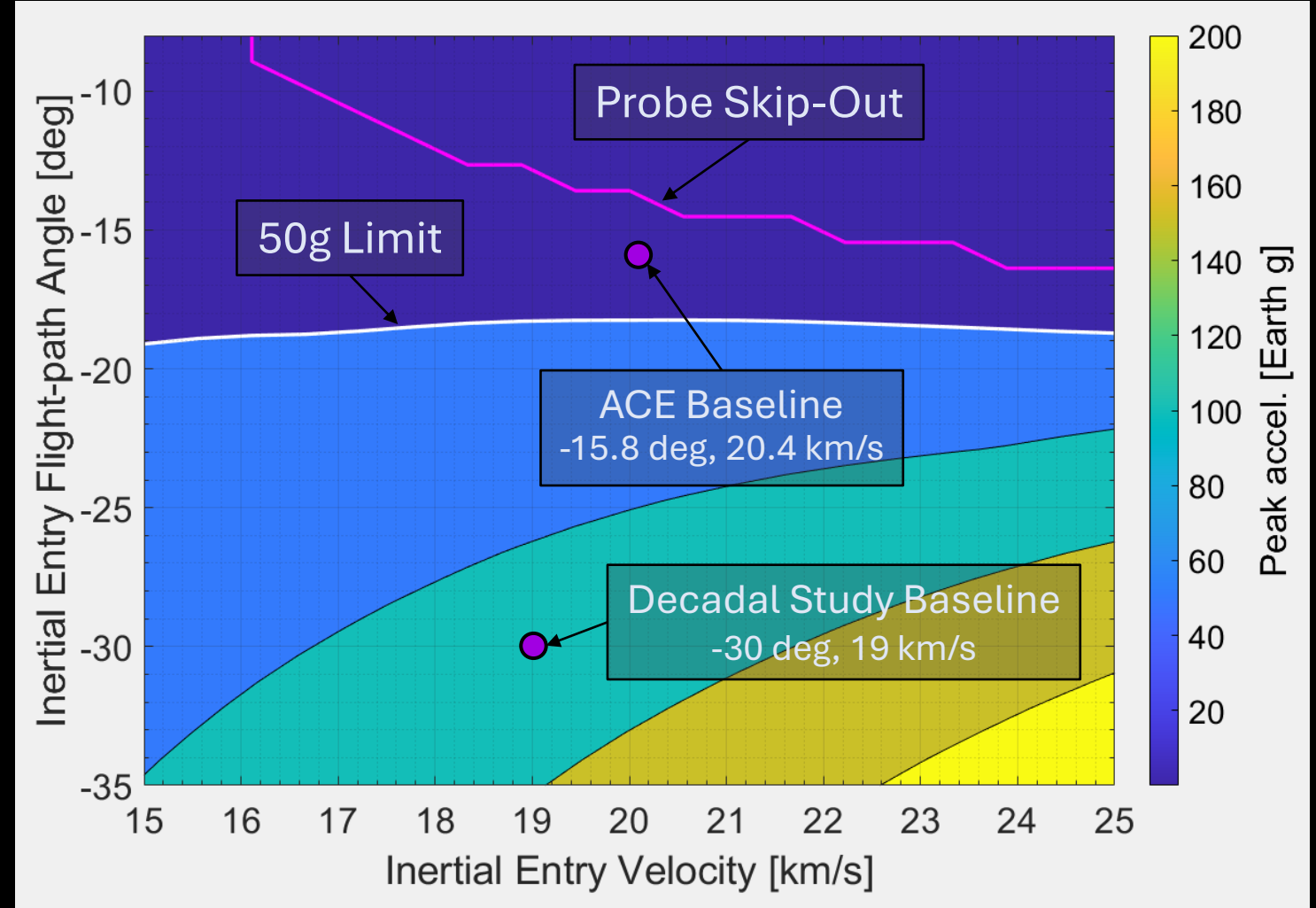


Name	MEV Mass (kg)	Power (W)	Data Collection	Measurements
Quadrupole Mass Spectrometer (QMS)	22.4	~86W (Inst) ~110W (heater)	- HS jettison to 10+ bar - Rate: 20 kbps	Abundance of ions; isotopic composition
Atmospheric Structure Instrument (ASI)	3.1	11.3	- Entry to 10+ bar - Entry Mode Rate: 18 bps - Post Parachute deploy Rate: 18 bps	Temperature, pressure, acceleration
Ortho-Para H ₂ Detector	1.3	5.2 (Avg) 1.3 (Standby)	0.1 to 10+ bar - Data: 1 Mbits total data	Ratio of ortho to para hydrogen -> temperature profile, atmospheric dynamics
Nephelometer	5.3	5.8 (Instrument) 7.8 (heater)	0.1 to 10+ bar - Rate: 10 bps	Particle size/ distribution/ concentration
Helium Abundance Detector (HAD)	1.7	1.2	2.5 to 10+ bar - Rate: 2 bps	He concentration, isotopic composition
Net Flux Radiometer (NFR)	2.9	6.2	0.1 to 10+ bar - Rate: 124 bps	Net radiative flux at different levels of atmosphere -> heat transportation

Threshold Instruments

Entry Design Considerations

- Key trades:
 - Steeper entry drives up peak heat rate and peak g-load
 - Shallower entry increases heat load and TPS thickness (i.e. mass)
- Peak g-load $\leq 50g$ (desired but not required)
 - Decadal-study peak g's = 114g
- Peak g's driven by:
 - Flight-path angle (primarily)
 - Entry speed (atmosphere relative)
- Achievable flight path angles driven by ring-avoidance constraint
 - Imposed constraint to avoid flight through Uranus's rings from ϵ ring down to cloud tops
 - May fly through ϵ - ν and ν - μ gaps
 - Baseline design has Probe enter before ring-plane crossing with Carrier passing through ϵ - ν gap
 - Viable trajectories ultimately driven by Uranus approach geometries



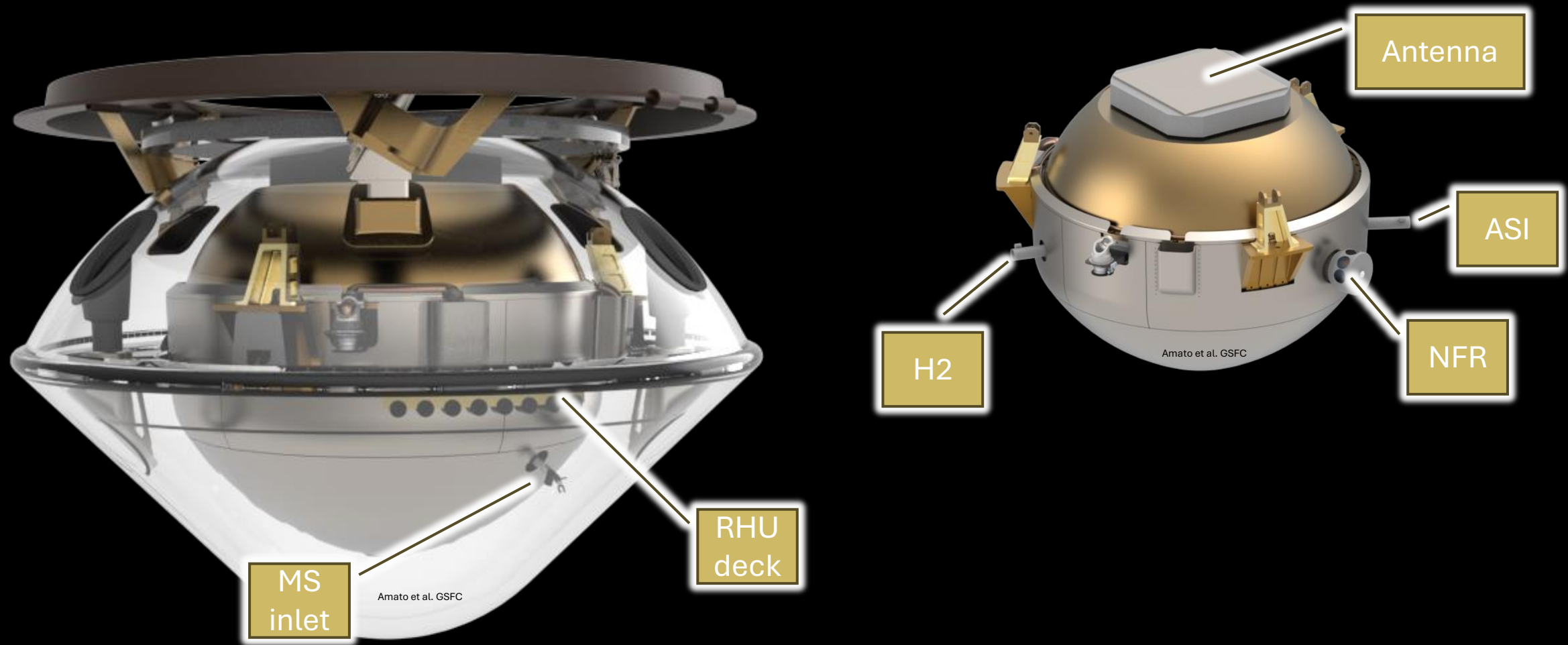
UOP Probe Entry System

- Design choices and Heating – Looking at shallower entry angles for a few reasons including reducing G loads for the instruments. Impacts entry system analysis and heating. Probe DV mass also impacts design.
- Heat shield Thermal Protection System – evaluating two choices. HEEET, which is a TRL 6 system can handle the range of entry conditions and accommodates larger Probe. 3MDCP, another variant of 3-D woven is more restrictive due to manufacturing thickness and scale limitations. 3MDCP was the TPS of choice for the Decadal design.
- HEEET heat shield Engineering Test Unit shown in the Figure was 1m diameter, built and tested for a more demanding Saturn entry conditions and has demonstrated capability to accommodate the desired lower entry flight path angle for the current Uranus Probe to achieve lower g-load.
- Possible HEEET configurations ;
 - Working cone angle, structure, tiles, thickness
- More design and trade work will be planned.



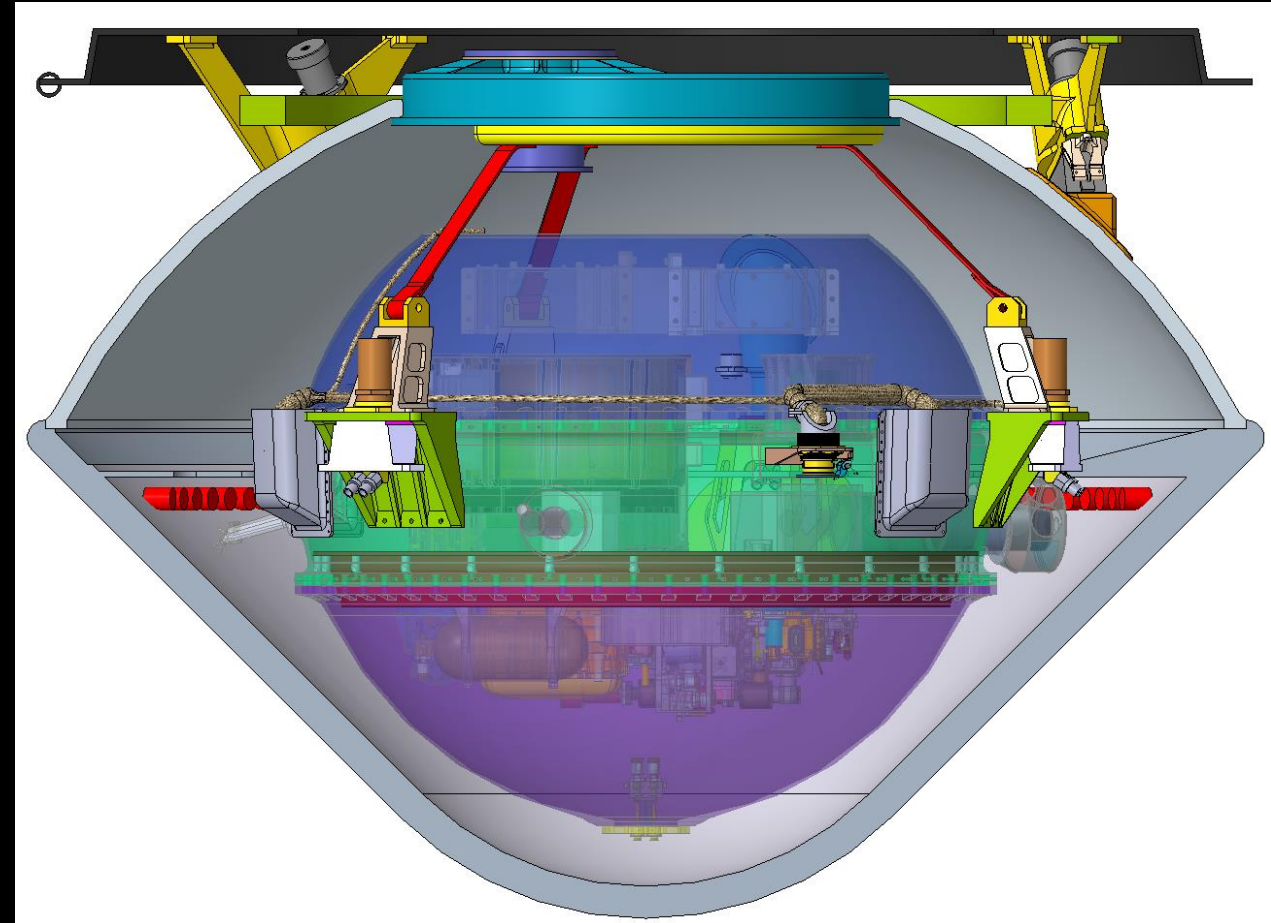
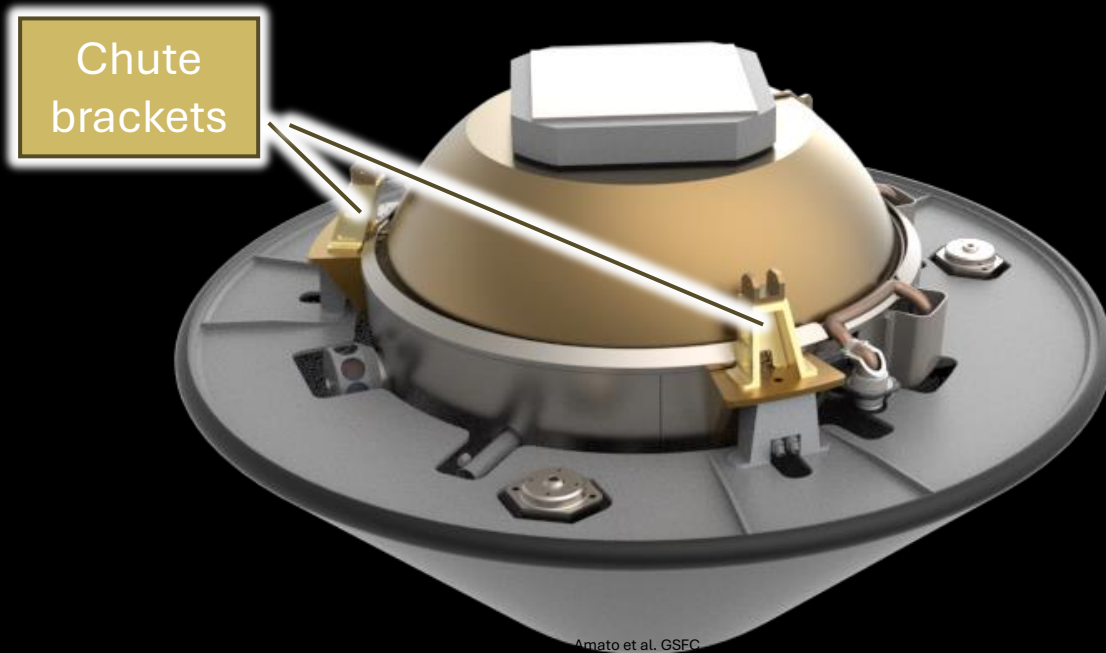
UOP Probe and Probe Descent Vehicle

- Basic structure design – GSFC team concept

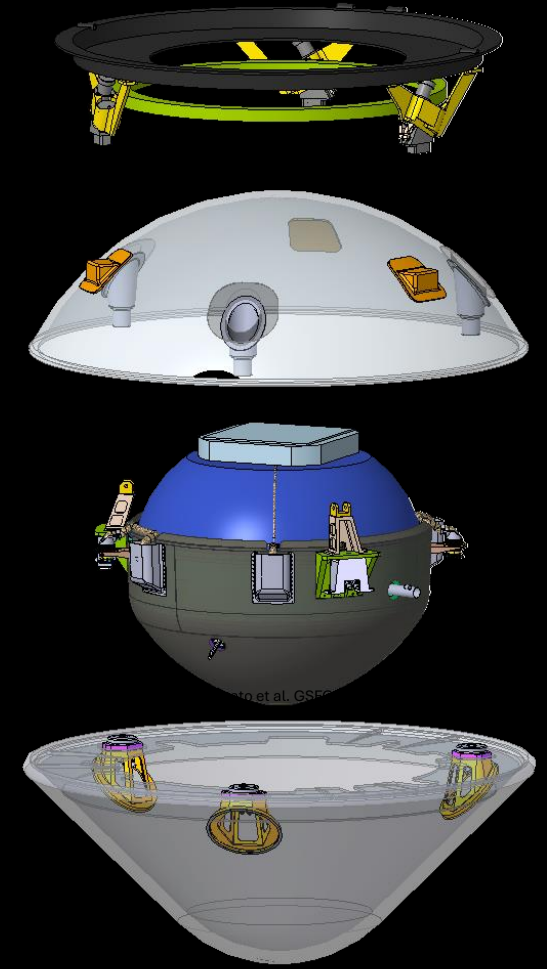
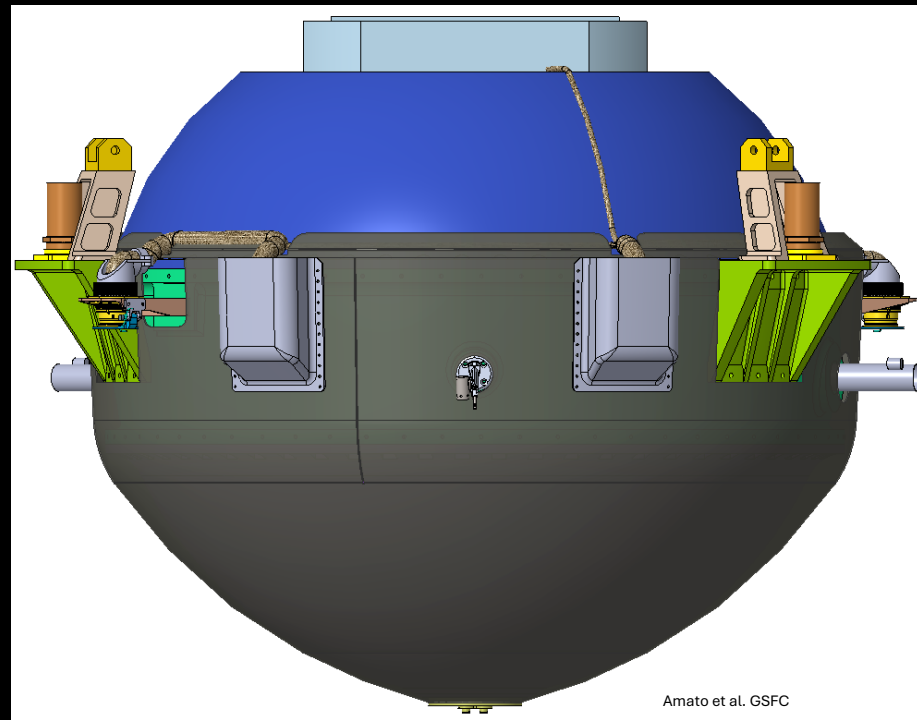
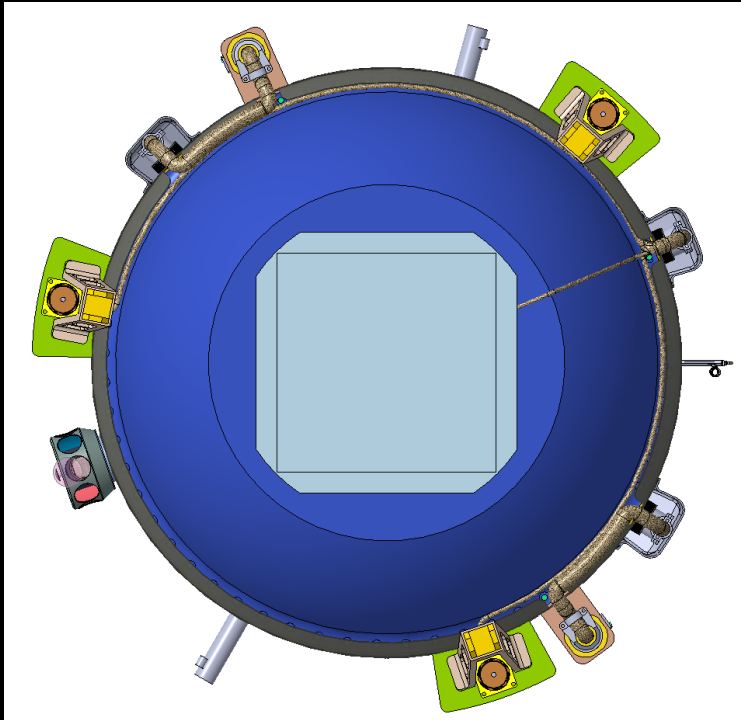


UOP Probe and Probe Descent Vehicle

- Interface within the entry systems – CAD model with a few labels



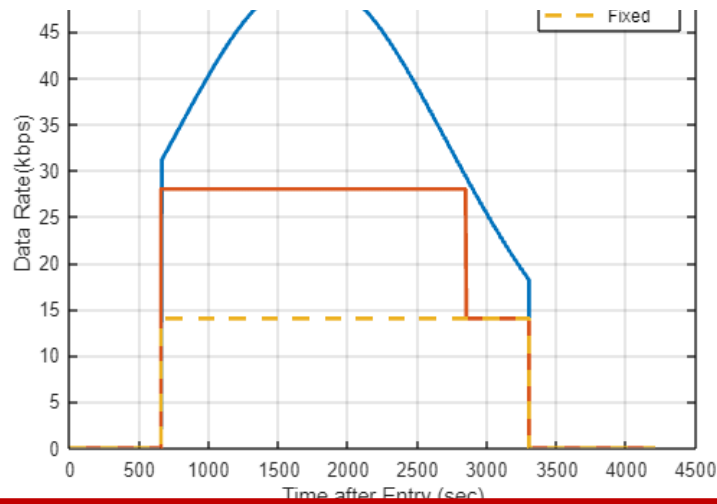
UOP Probe and Probe Descent Vehicle (D.V.)



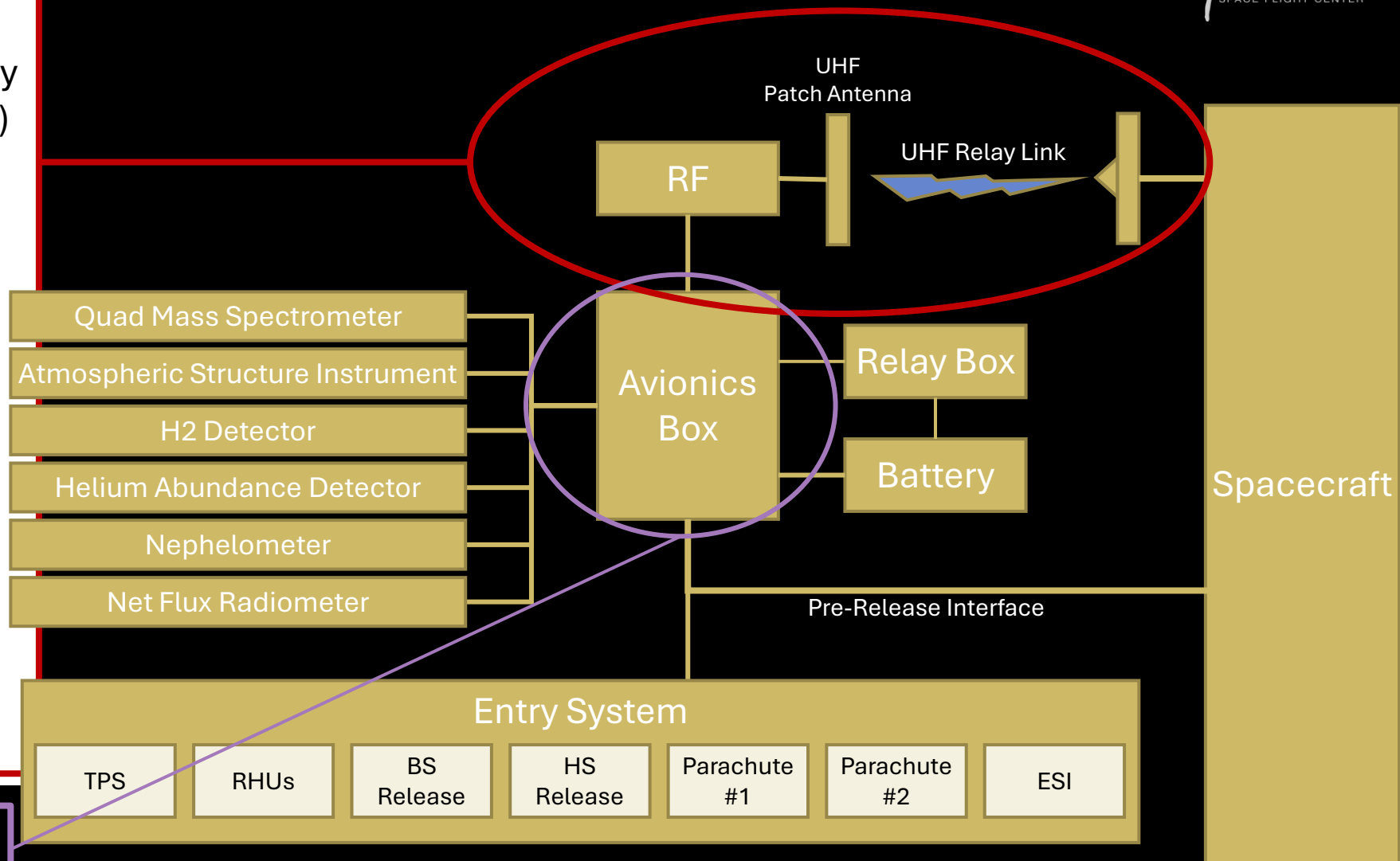
UOP Probe High-Level D.V. Block Diagram

Link assumptions:

- Adaptive data rate (37 Mbits, entry through descent, 6dB link margin)
- Single string
- No relay until backshell is jettisoned
- Negligible interference from fly-through of Uranus rings



Avionics approach is similar to DAVINCI avionics with a number of modifications.



Future Work / Trades

- Data sufficiency before flying through rings, vs impact of fly-through on link
- Potential Mass Savings Opportunities
 - Component vs system level sealing
- Selected Redundancy Approach
- Thermal design
- UHF antenna
- Probe Concept Enhancements
 - Post processing relay data vs symbol rate storage
 - Secondary/rechargeable battery

Summary

- Uranus presents some unique challenges to UOP probe design.
- Our Team is advancing early design work, leveraging past experience.
- Engineering studies must be worked in close coordination with the science community, to improve how design choices and optimization can provide the best probe system design and resulting science.



Back Up