Uranus Flagship-Class Orbiter and Probe Using Aerocapture

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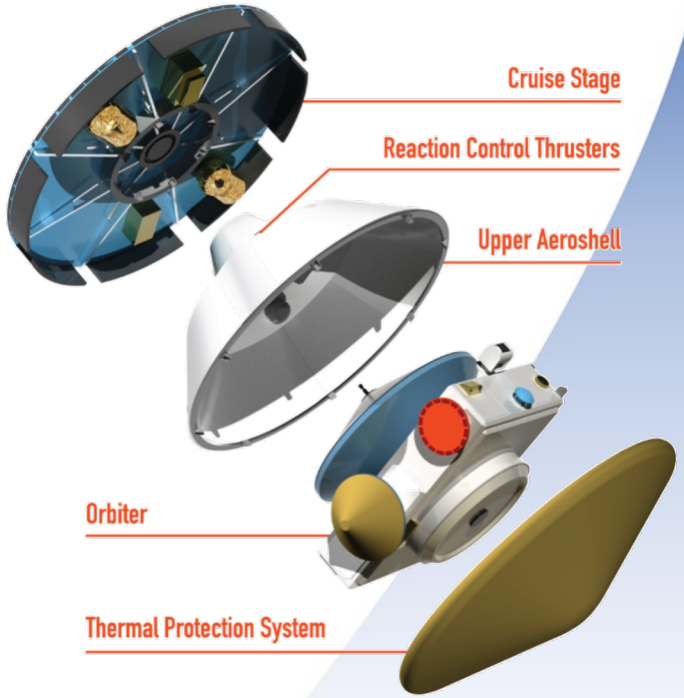
Jet Propulsion Laboratory



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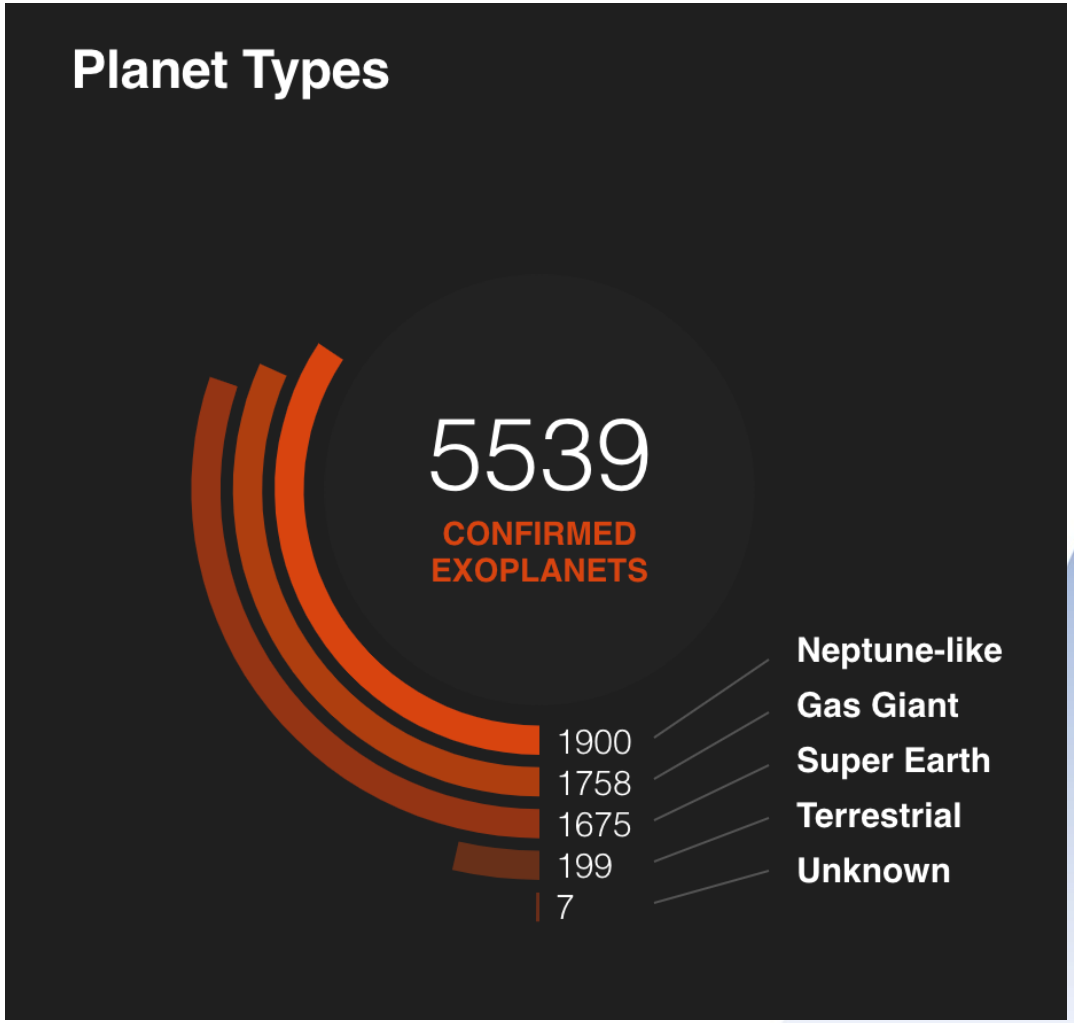
Why the Ice Giants?

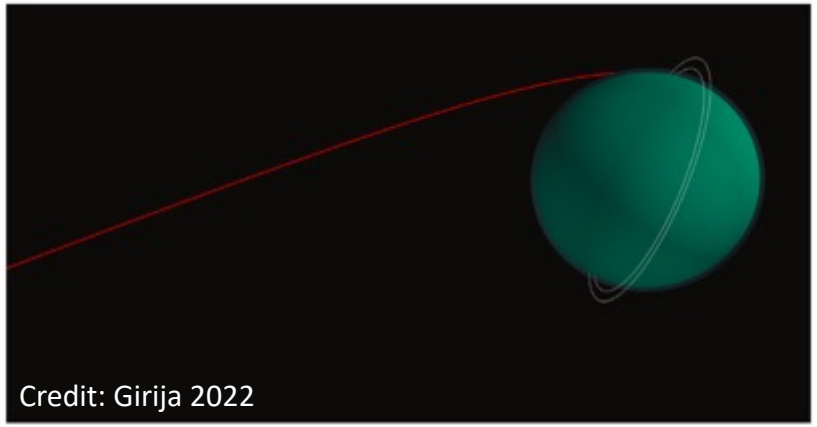
- Uranus and Neptune (Ice Giants) have only been visited by Voyager 2 through a flyby
- Uranus has interesting obliquity; Neptune has interesting moon: Triton
- Many exoplanets are Uranus and Neptune like
- **"The highest priority new Flagship mission for the decade 2023-2032 is the Uranus Orbiter and Probe mission" – Planetary Decadal Survey (2022)**
  - Uranus Spring Equinox in 2050. Scientific desire to observe Uranus prior to 2050 to see the planet in a posture not seen by Voyager 2
- **Decadal Survey also mentions aerocapture as a technology that should be incentivized**



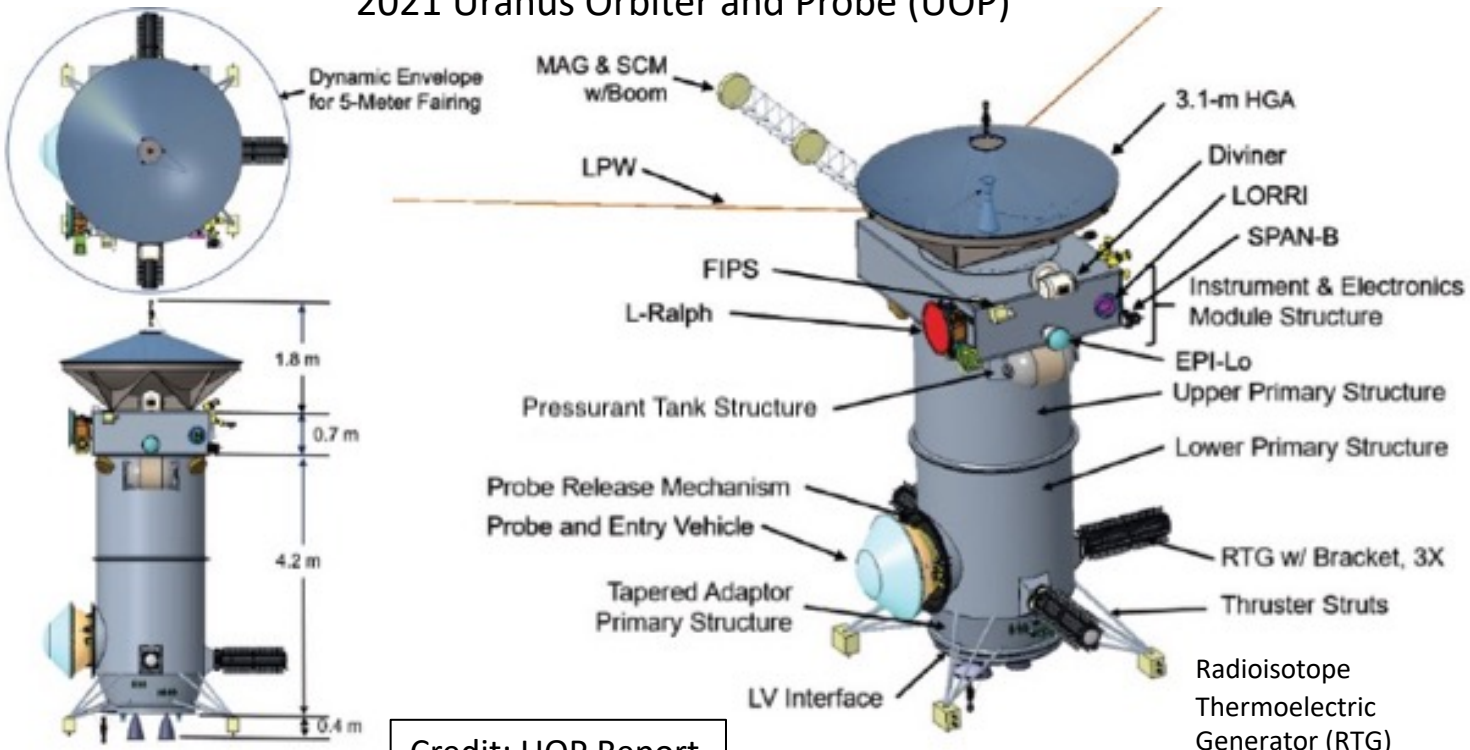
Credit: Exoplanets.nasa.gov (accessed Nov. 27, 2023)

Uranus Flagship Concept

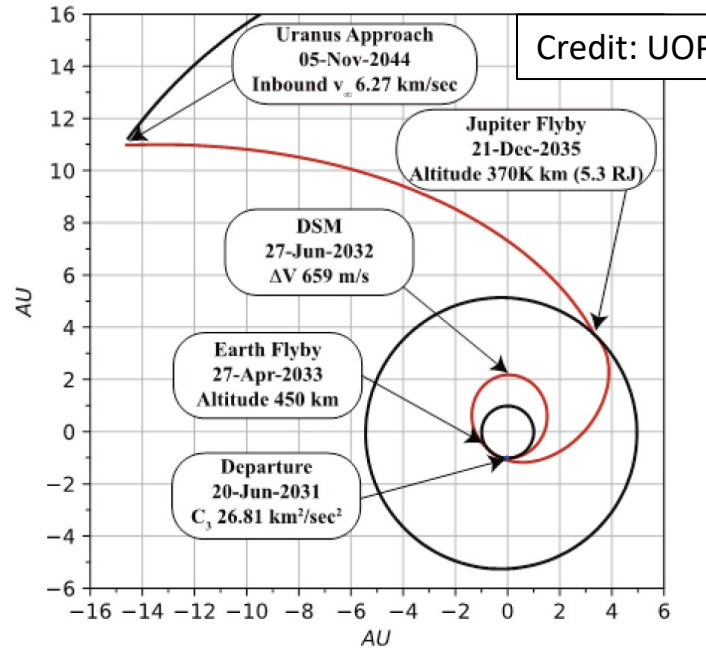
- **2021 Uranus Orbiter and Probe (UOP) mission concept study**
  - 2023-2032 Planetary Decadal top Flagship-Class destination
  - 2031/2032 launch date; 13 years of transit
  - **1000 m/s ΔV for Uranus Orbit Insertion (1800 kg fuel) – 60-70% of launch mass is fuel**
  - Nuclear power source lifespan degrades after 17 years



2021 Uranus Orbiter and Probe (UOP)



Credit: UOP Report

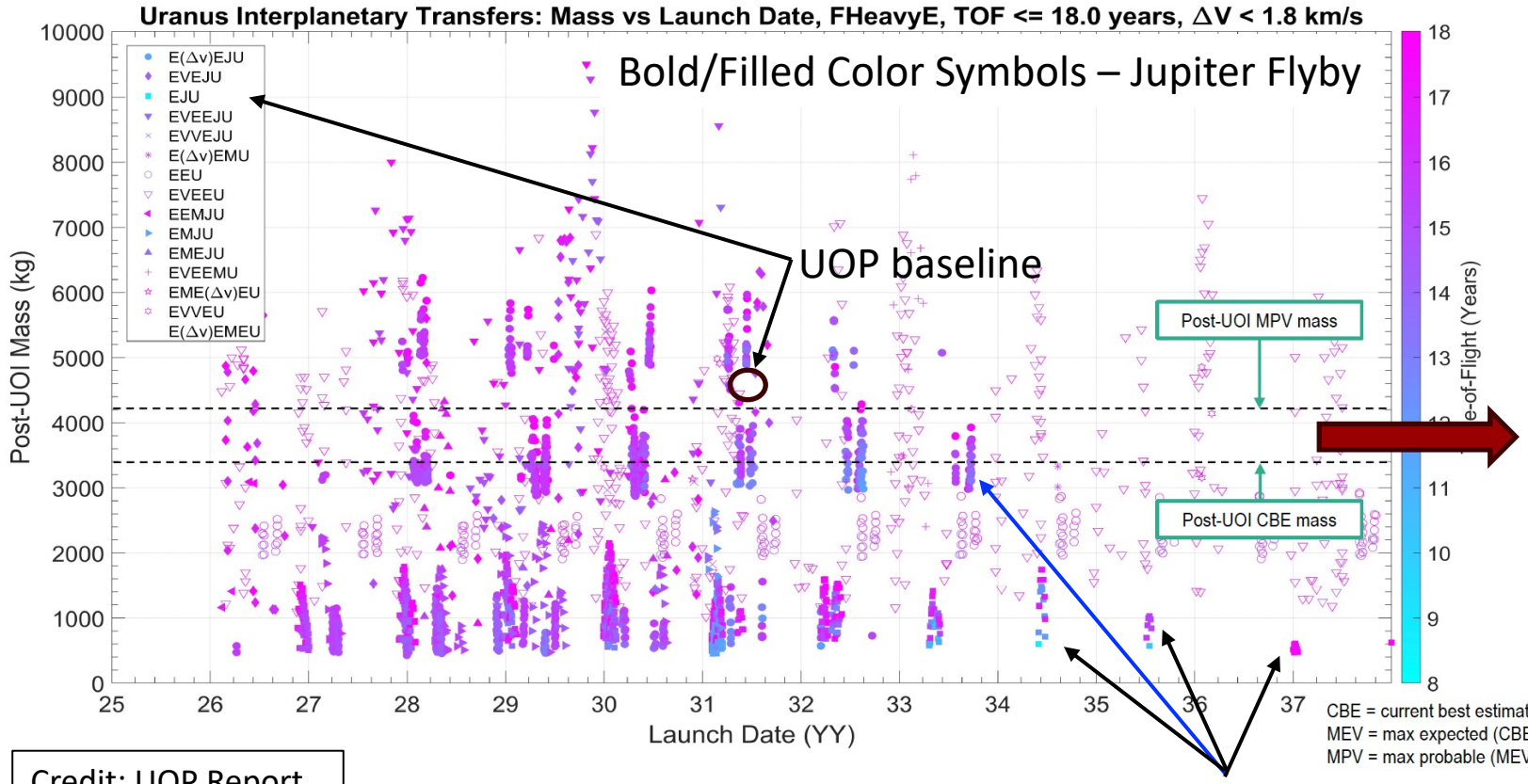


Credit: UOP Report

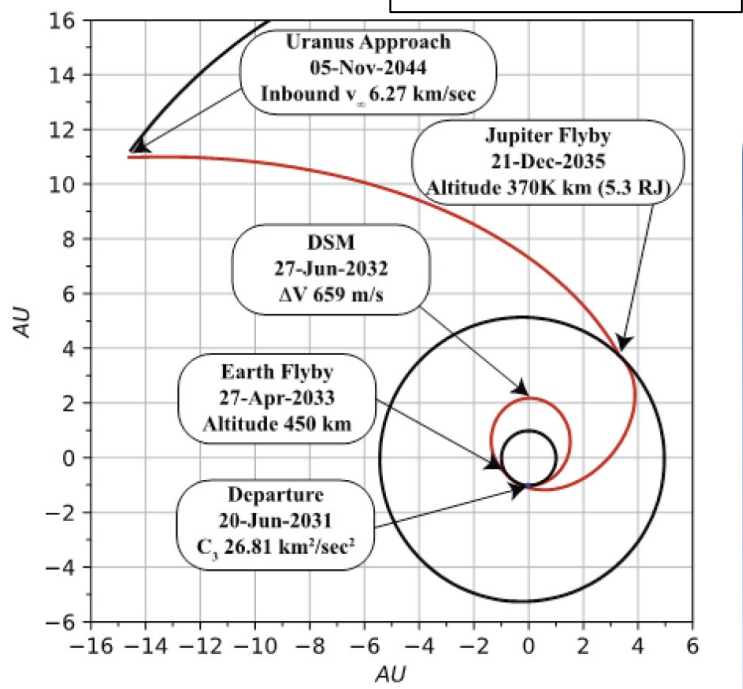
Exhibit 3-25. *Baseline interplanetary trajectory (launch period center case).*

Uranus Orbiter and Probe Challenges

- **Needed a 2031/2032 launch date to get to Uranus in 2044-2045**
  - Now in 2023, need a flagship mission, which has not been approved, to be ready in 8-9 years
- **Needed Jupiter fly-by**
  - Jupiter fly-by reduced opportunities after 2033 launch date



Credit: UOP Report



Credit: UOP Report

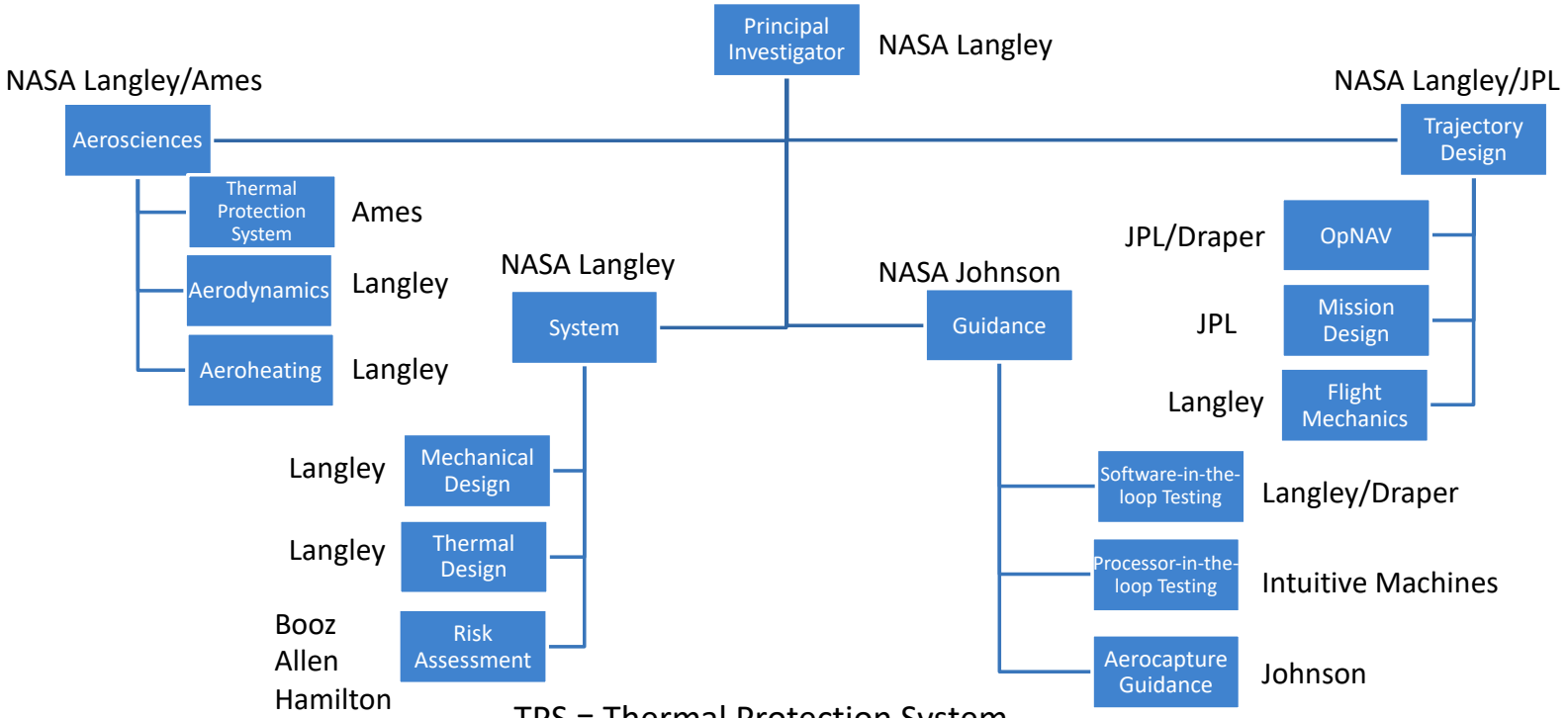
Exhibit 3-25. *Baseline interplanetary trajectory (launch period center case).*

UOP/propulsive limited by v_∞ arrival

Latest Jupiter options

Aerocapture for Uranus Project

- Early Career Initiative (ECI) sponsored by NASA Space Technology Mission Directorate
- Multi-centered, multi-disciplinary team to design an end-to-end aerocapture concept
- Objective: Use heritage entry vehicle configurations to provide a feasible aerocapture concept to take a mature Uranus orbiter and probe concept to orbit



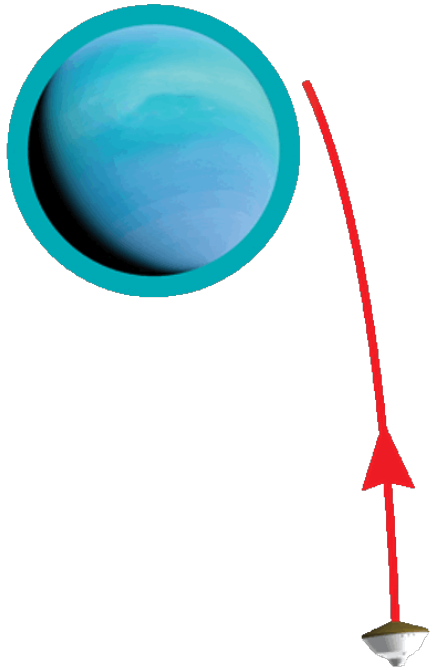
TPS = Thermal Protection System
GNC = Guidance, Navigation, and Control
OpNAV = Optical Navigation

- 9:50 am – 10:10 am: Mission Design/Interplanetary Navigation
- 10:10 am – 10:30 am: Aerocapture Trajectory
- 10:30 am – 10:50 am: Guidance, Navigation, and Control
- 1:00 pm – 1:20 pm: Aerodynamics
- 1:20 pm – 1:40 pm: Aerothermodynamics
- 1:40 pm – 2:00 pm: Thermal Protection System
- 2:00 pm – 2:20 pm: Mechanical System

Outline

- What is aerocapture?
- Why Ice Giants?
- Aerocapture team
- **Uranus Flagship Concept**
- **Challenges with Uranus Orbit and Probe**
- **Aerocapture Solutions for Uranus Flagship**
- **Aerocapture Sensitivities**

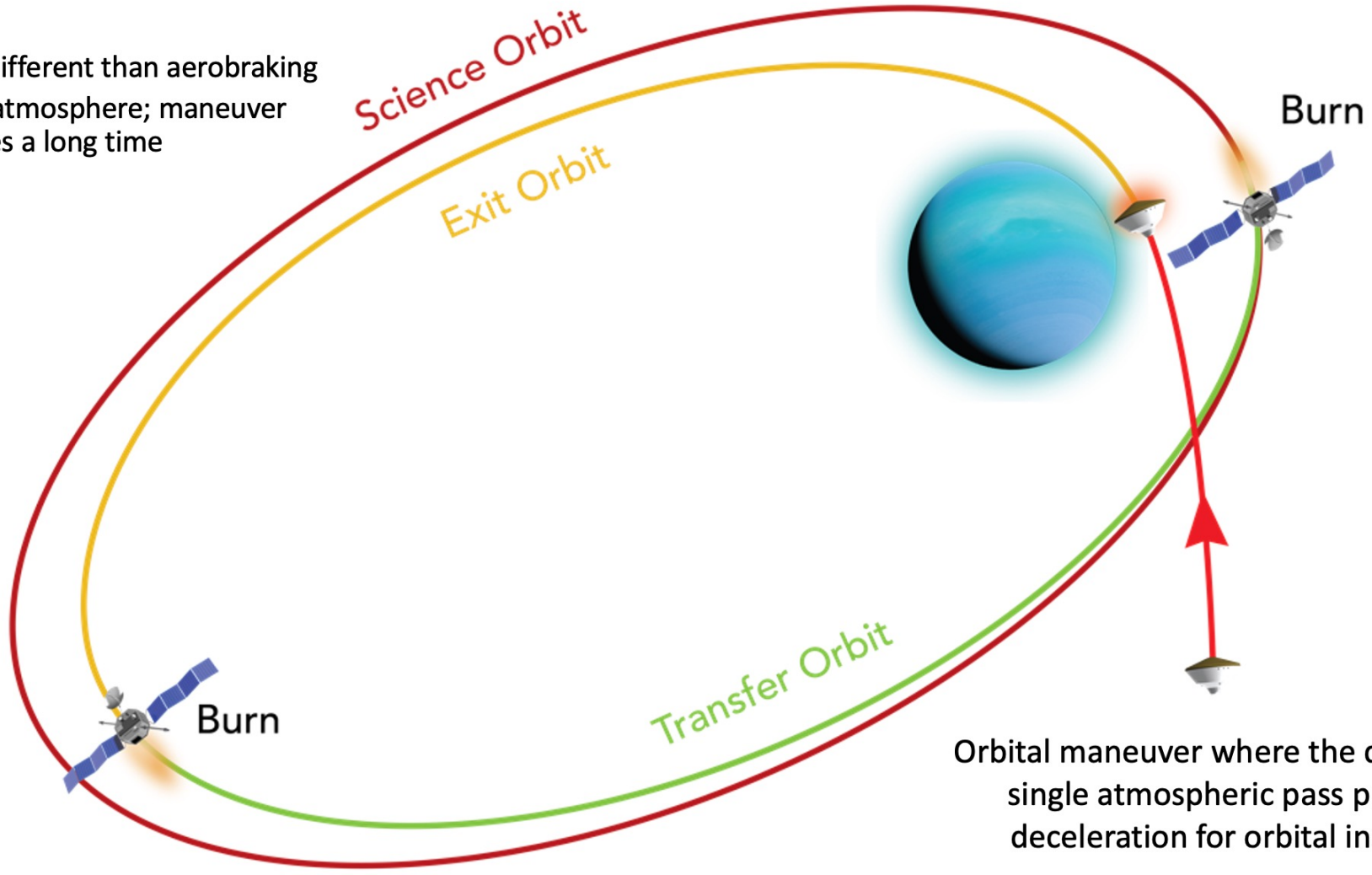
What is Aerocapture?



Orbital maneuver where the drag from a single atmospheric pass provides deceleration for orbital insertion

What is Aerocapture?

Aerocapture is different than aerobraking
Which skims atmosphere; maneuver takes a long time



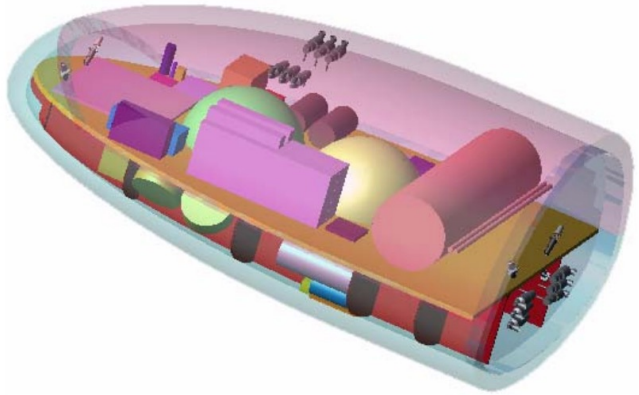
Orbital maneuver where the drag from a single atmospheric pass provides deceleration for orbital insertion

Aerocapture for Uranus Concept

- Several aerocapture concepts for Ice Giants (especially Neptune) considered in the past
- Concepts required new vehicle concepts – ellipsled for more lifting control, trailing ballute for larger drag area
- Concept presented here relies on heritage, 70-deg. sphere-cone flown for Mars Entry, Descent, and Landing (EDL). Studied 4.5 m and 5 m diameter vehicles. UOP as the payload.

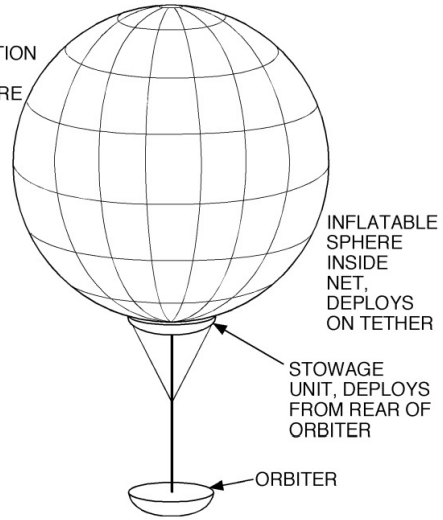
Past Concepts for Ice Giants Aerocapture

Ellipsled



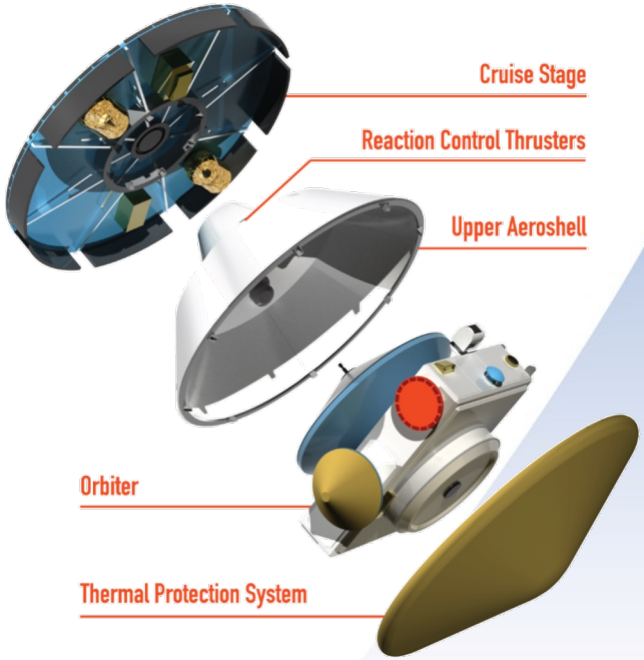
Credit: Lockwood 2006

Trailing Ballute

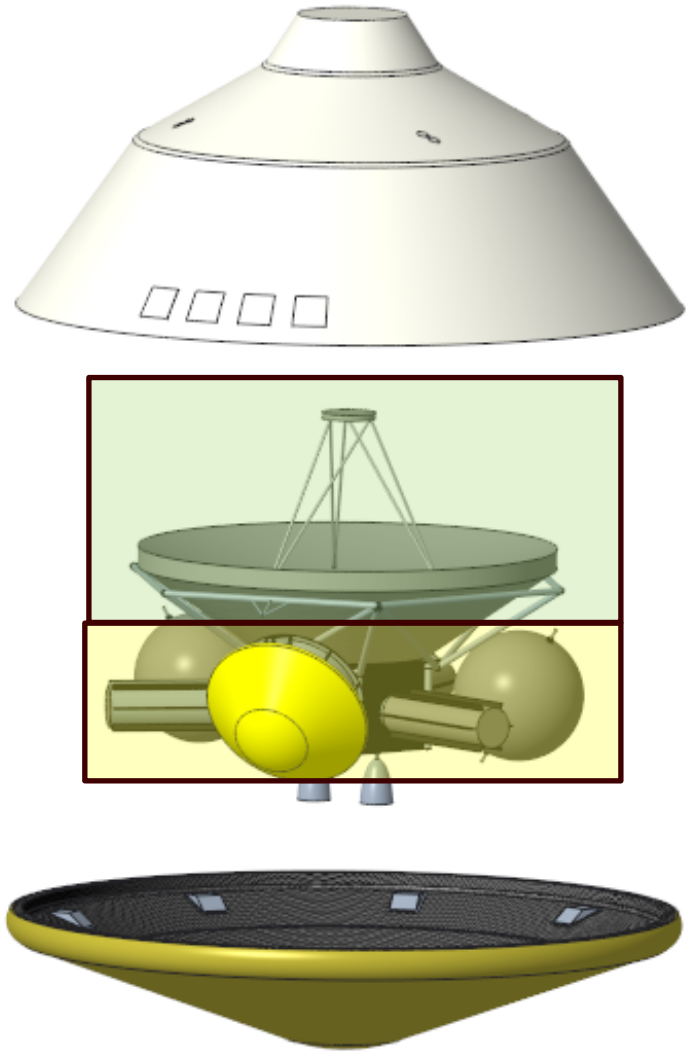


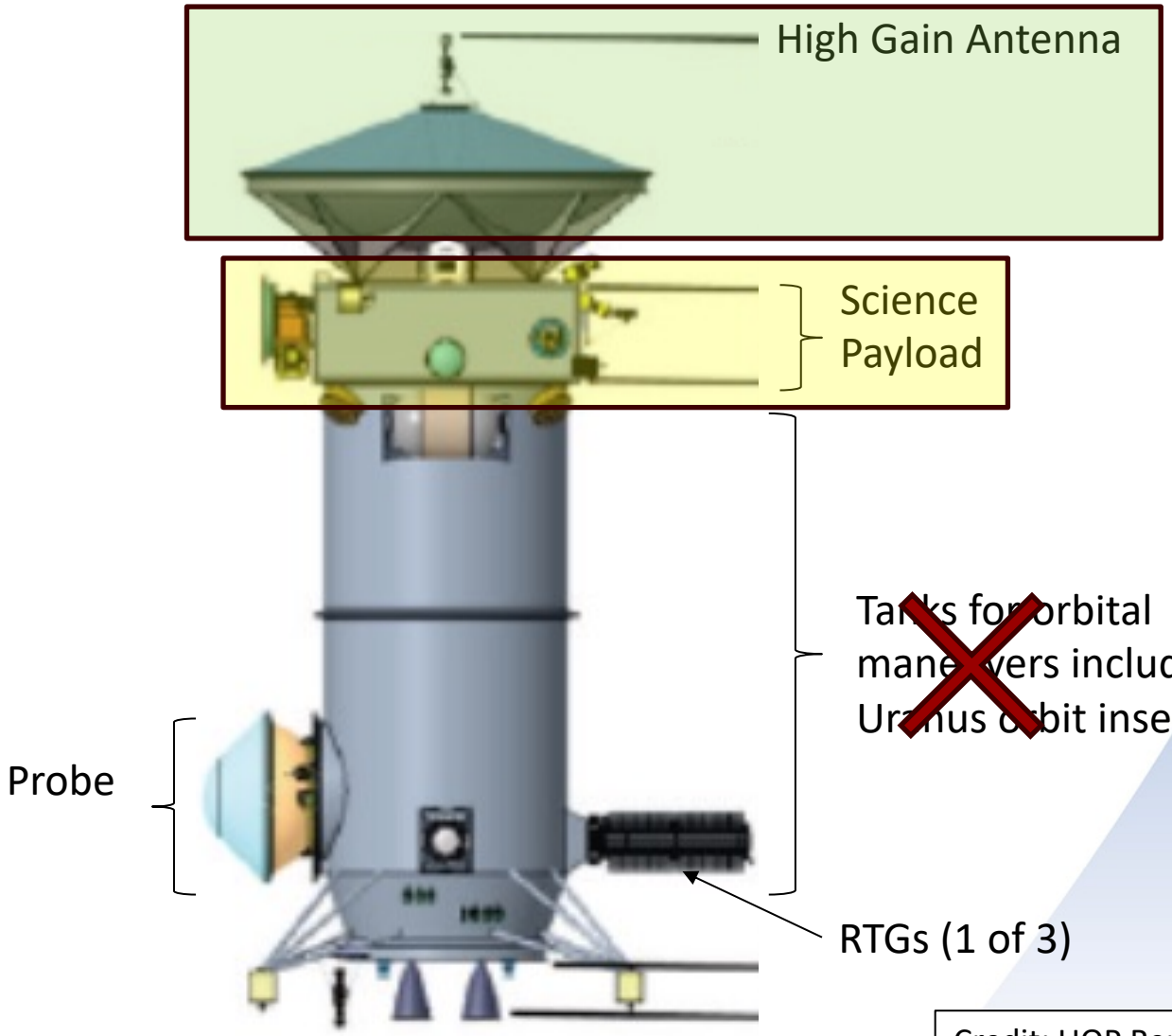
Credit: McRonald 2000

Current Concept – Heritage, Blunt Body



Vehicle Comparison

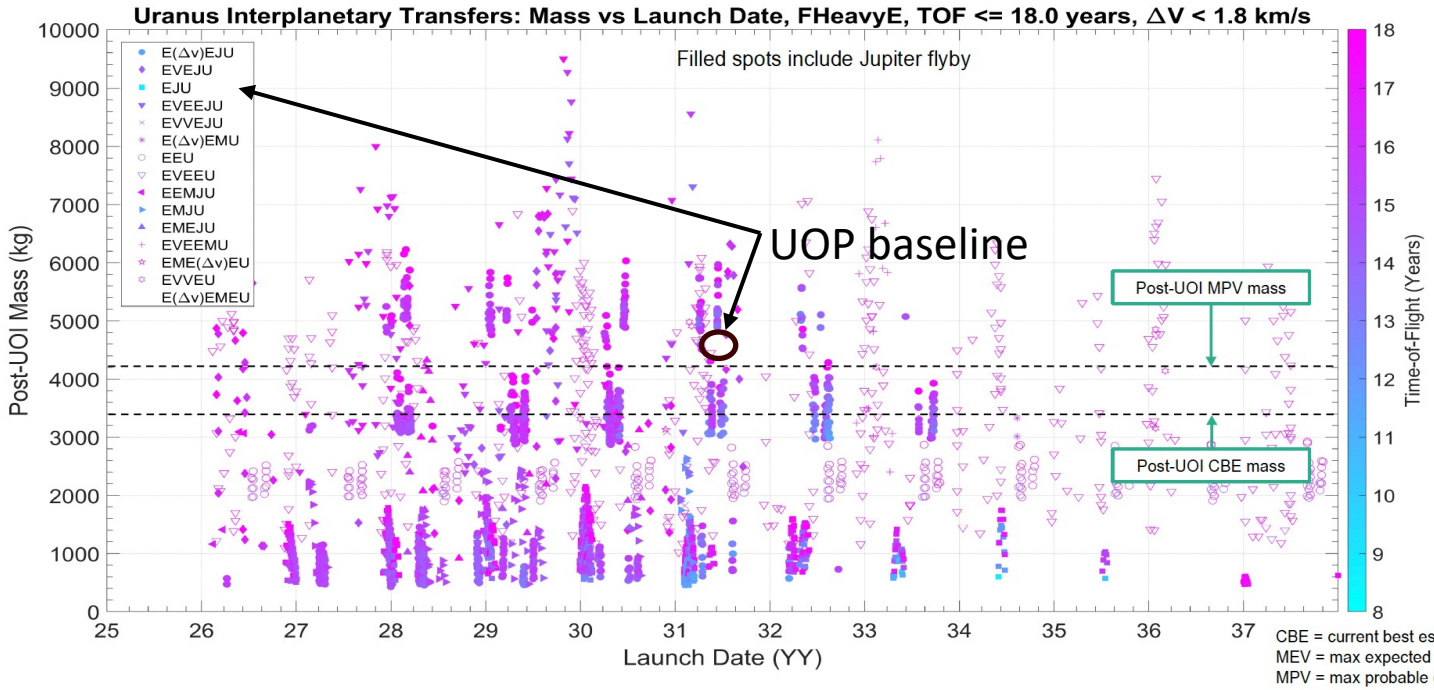




Credit: UOP Report

Mission Design and Navigation Considerations

- For fully-propulsive missions, Jupiter fly-by is crucial to attain a lower ΔV (~1 km/s) that was desired by the Mission Concept Study. Limits choices for post-2033 launch
- Aerocapture concepts use existing heavy launch vehicles (e.g. Falcon Heavy) and can reach the planet in 9 or less years
- Aerocapture provides many launch opportunities in 2036 and 2038 to reach Uranus by the Spring Equinox
- See Mages et al. (AIAA 2024-XXXX) for mission design and navigation considerations



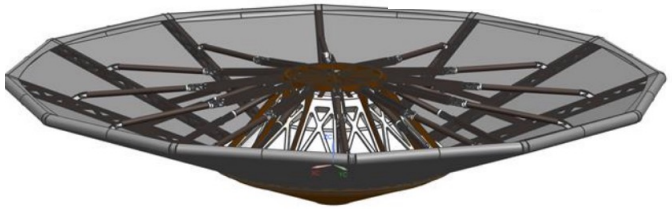
Credit: UOP Report

Mechanical System Design Considerations

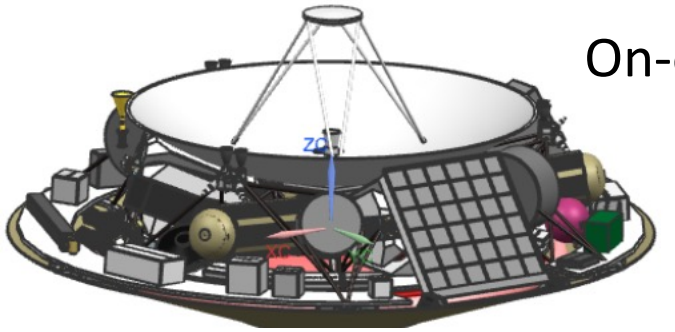
- Current concept houses science instrumentation, High Gain Antenna (HGA), three Radioisotope thermoelectric generators (RTGs), probe(s)
- Thermal control based on heat generated by RTGs still under design
- Mechanical considerations discussed by Gomez-Delrio et al. (AIAA 2024-XXXX)

Configurations for Uranus Aerocapture from another recent concept

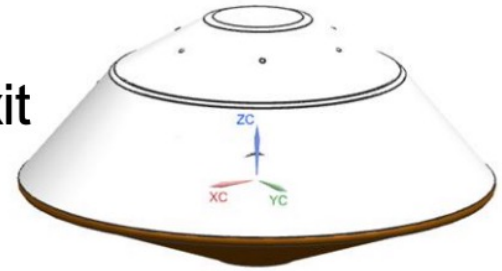
Aero-entry



On-orbit

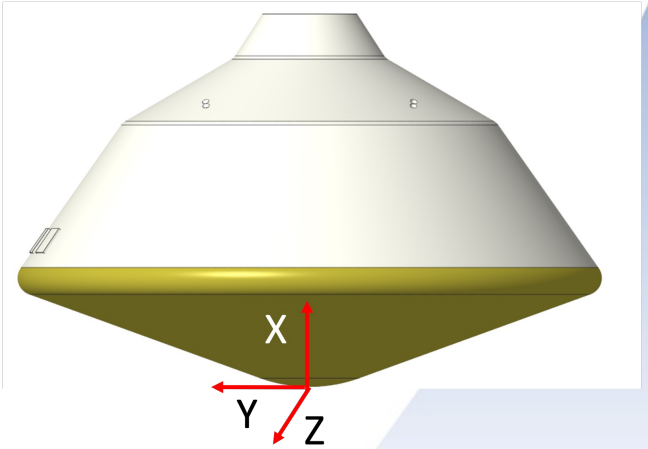


Aero-exit



Credit: Elliott 2020

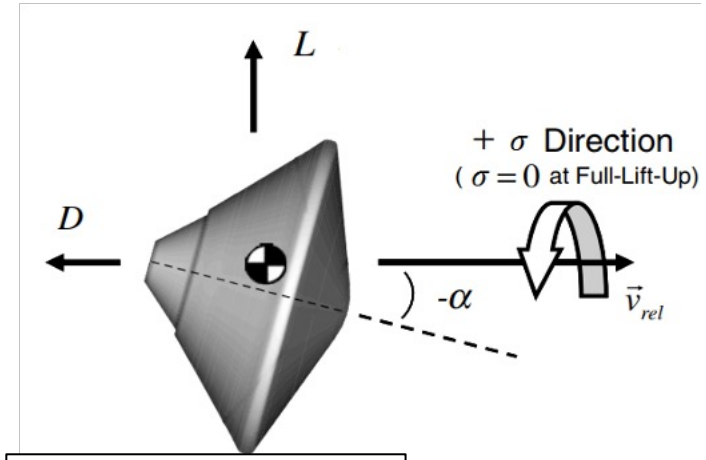
Current Concept: Fixed aeroshell during hypersonic flight



Guidance and Control Considerations

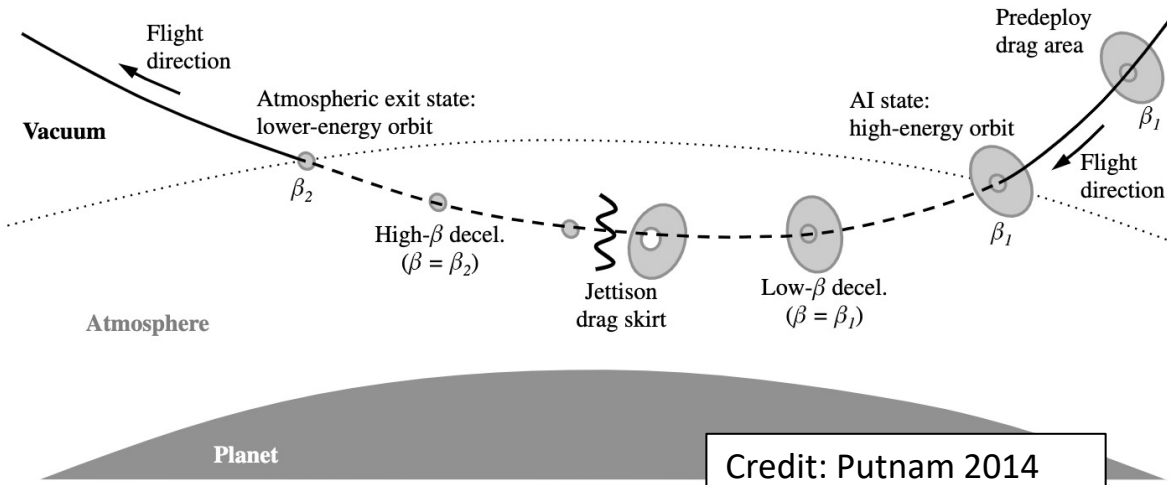
- Aerocapture studies have shown two types of control actuation: lift-control and drag-control. Within lift-control, there are two modes: controlling the bank angle only or control angle of attack and sideslip angle directly (direct force control)
- Current concept shows robust performance with bank angle control at lift-to-drag ratio of 0.25 (very similar to concept of operations used by Mars Science Laboratory in 2012 and Mars 2020). See Matz et al. (AIAA 2024-XXXX) for guidance and control considerations.

Bank Angle Modulation
(demonstrated at Earth and Mars)



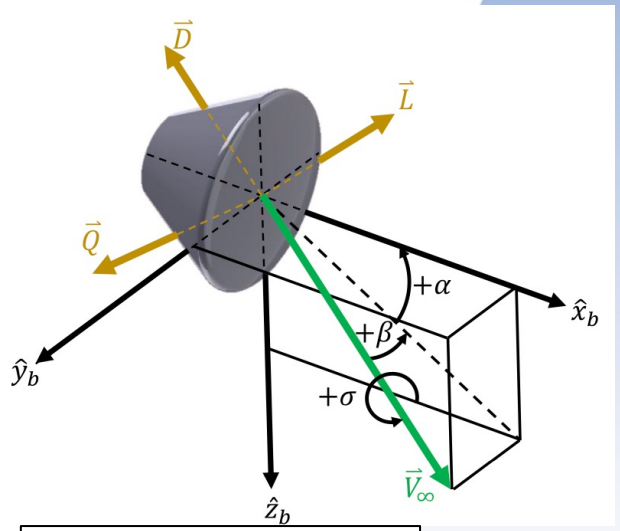
Credit: Heidrich 2019

Drag Modulation



Credit: Putnam 2014

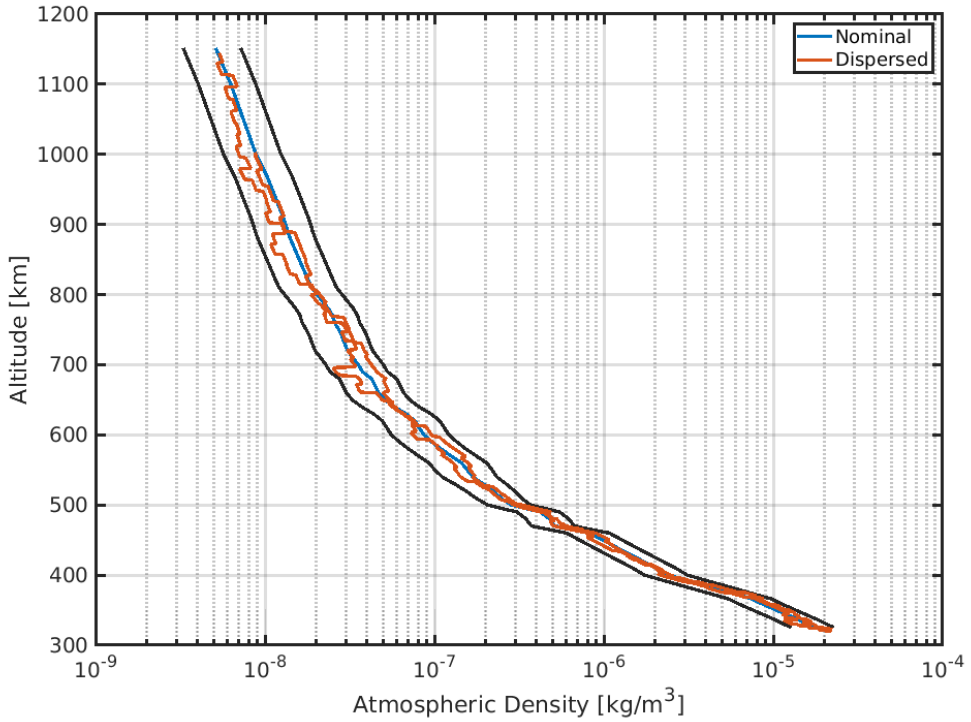
Direct Force Control

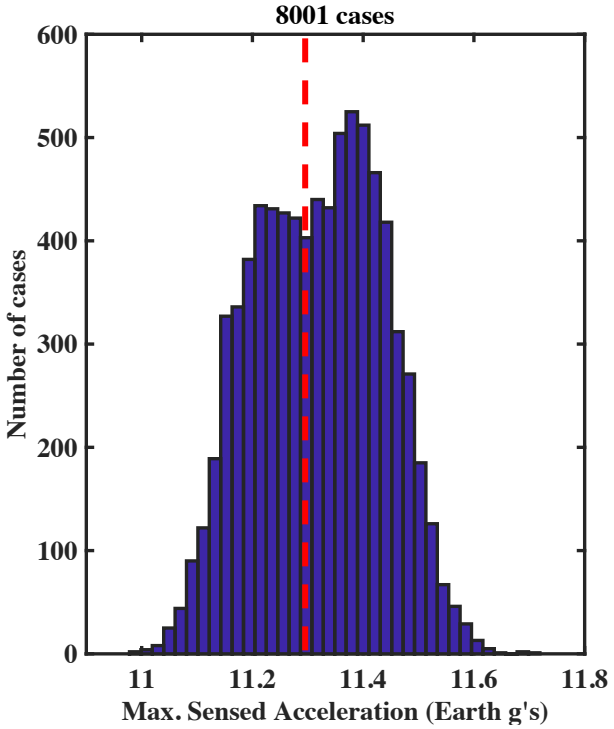


Credit: Deshmukh 2020

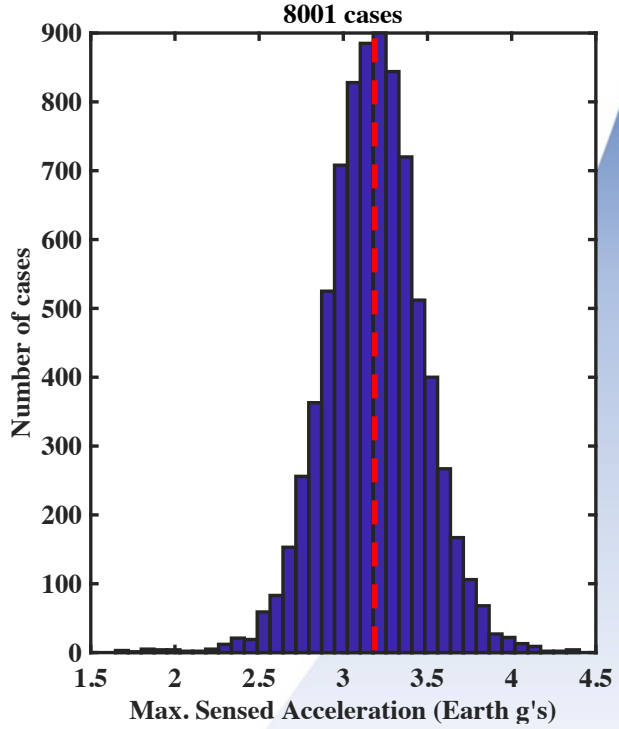
Trajectory and Aerocapture Performance

- Aerocapture has more benign environment than EDL missions, e.g. lower deceleration
- Uranus atmosphere has large uncertainties – atmosphere based on one fly-by and Earth-based observations
- Aerocapture trajectory shows robust performance with current concept (see Deshmukh et al. AIAA 2024-XXXX)





Mars 2020
(Mars EDL)

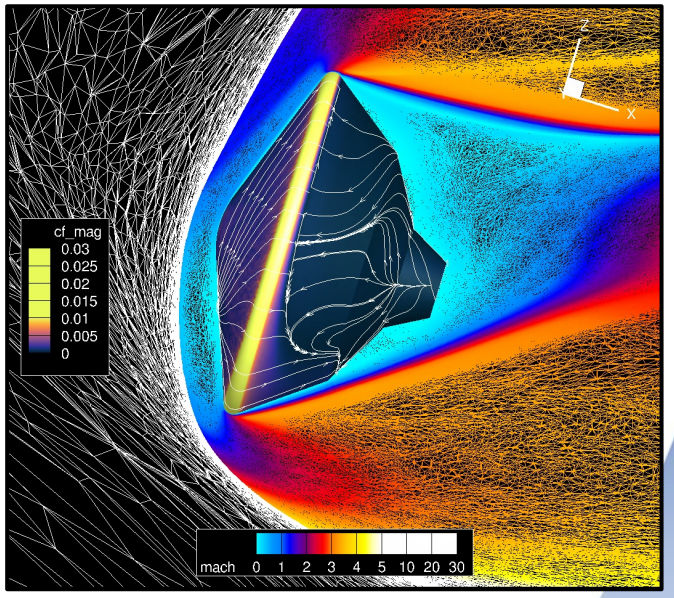


Current Concept
(Uranus Aerocapture)

Aerosciences and Thermal Protection System

- Uranus atmosphere consists of H_2-He as primary constituents
  - Small CH_4 at layers below peak entry heating
  - Current computation fluid dynamics (CFD) processes more validated for CO_2 (Mars, Venus) and N_2 (Earth, Titan) atmospheres
- Gas chemistry model development conducted for aerodynamic (see Shellabarger et al. AIAA 2024-XXXX) and aerothermodynamic (see Scoggins et al. AIAA 2024-XXXX) tools typically used for other EDL missions
  - Key observation: Radiative heating low at aerocapture speeds considered in the current concept
- Aerocapture peak heat flux and pressure low compared to other extreme EDL applications (including design of the probe for Uranus) – see Morgan et al. (AIAA 2024-XXXX)
  - Key observation: CPICA design within margins and manufacturing limits
  - Heatshield separation timing can affect TPS thickness by ± 5-8%

CFD Solution of Current Concept



Conformal PICA (CPICA)

Credit: NASA Ames

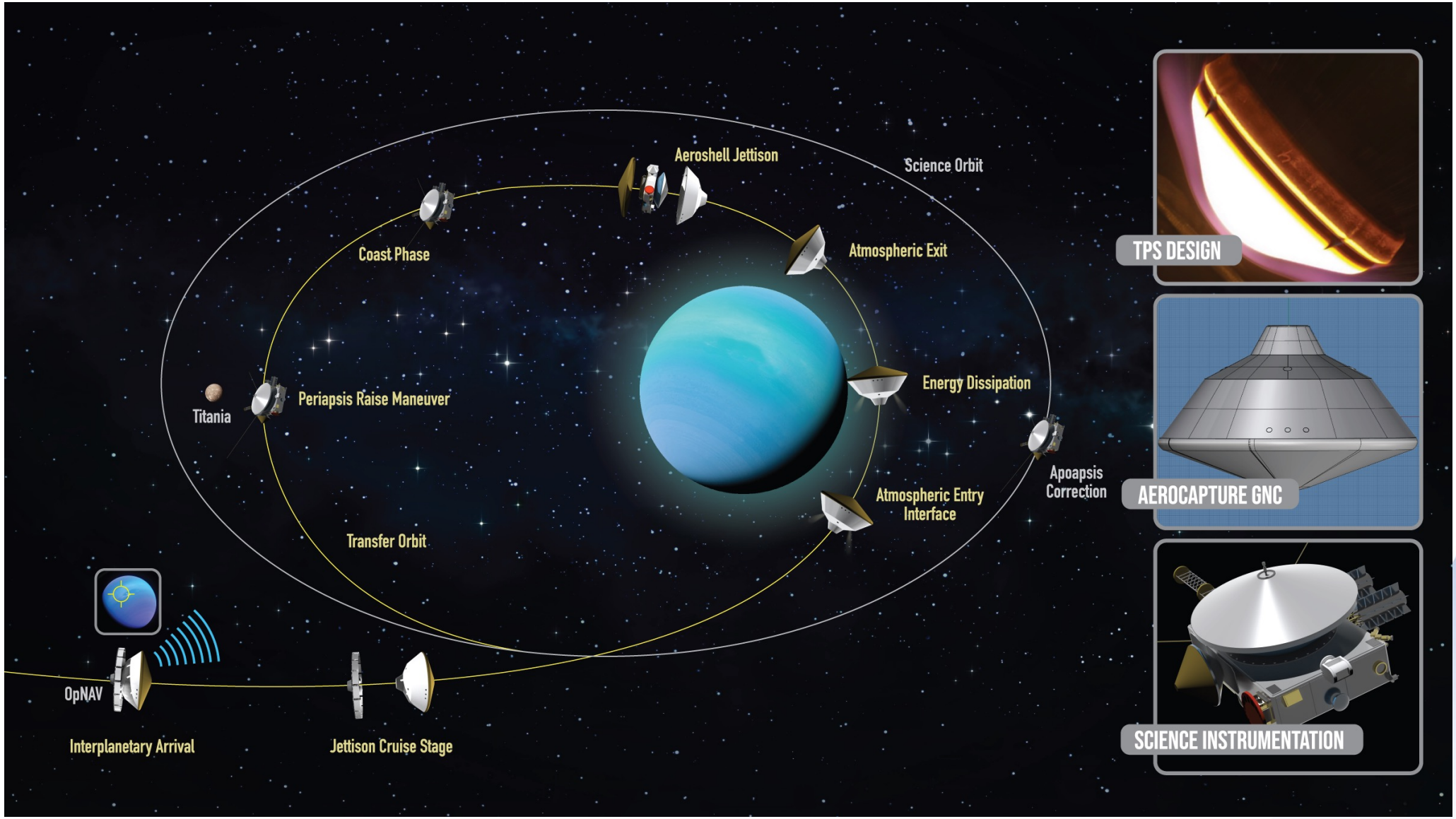
Summary

- Uranus is the prime Flagship-Class mission destination chosen by the Planetary Science Decadal Survey in 2022. Interest in visit to the planet before 2050 Spring Equinox
- Baseline Uranus mission from the Decadal Survey is a fully-propulsive orbit insertion concept called Uranus Orbiter and Probe. It takes 13 years to reach Uranus, has 60-70% of the launch mass as fuel, and needs launch dates in 2031 or 2032
- This Uranus Aerocapture study uses heritage, 70-deg. sphere-cone similar to Mars Science Laboratory and Mars 2020 to take the UOP payload to Uranus in 9 years or less with less fuel mass
- Aerocapture can utilize 2036 and 2038 launch opportunities to reach Uranus before 2050
- Seven additional papers on Tuesday (Jan. 9th) sessions of the GNC/AFM-sponsored EDL GNC special sessions will explore the design of the aerocapture system more in-depth

Acknowledgments

- The work is funded by the NASA Space Technology Mission Directorate (STMD)'s Early Career Initiative (ECI)
- The current project is part of the FY23 cohort and will continue through FY24
- External partners include Draper Laboratories, Intuitive Machines, and Booz Allen Hamilton

Questions


Aeroshell Jettison
Science Orbit
Coast Phase
Atmospheric Exit
Titania
Periapsis Raise Maneuver
Energy Dissipation
Apoapsis Correction
Atmospheric Entry Interface
Transfer Orbit
OpNAV
Interplanetary Arrival
Jettison Cruise Stage
TPS DESIGN
AEROCAPTURE GNC
SCIENCE INSTRUMENTATION