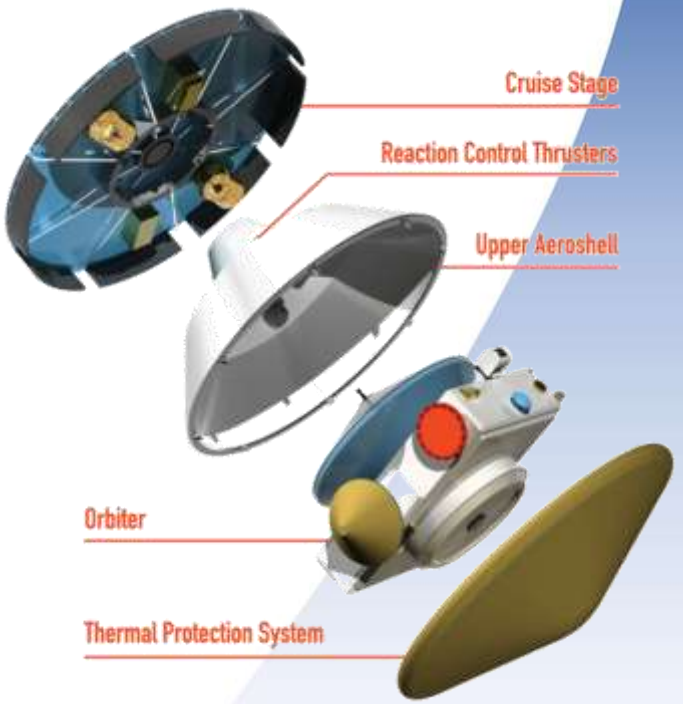
6-DOF Uranus Aerocapture Trajectory Analysis

Session: ICE GIANTS & GAS GIANTS

Abstract No : 7

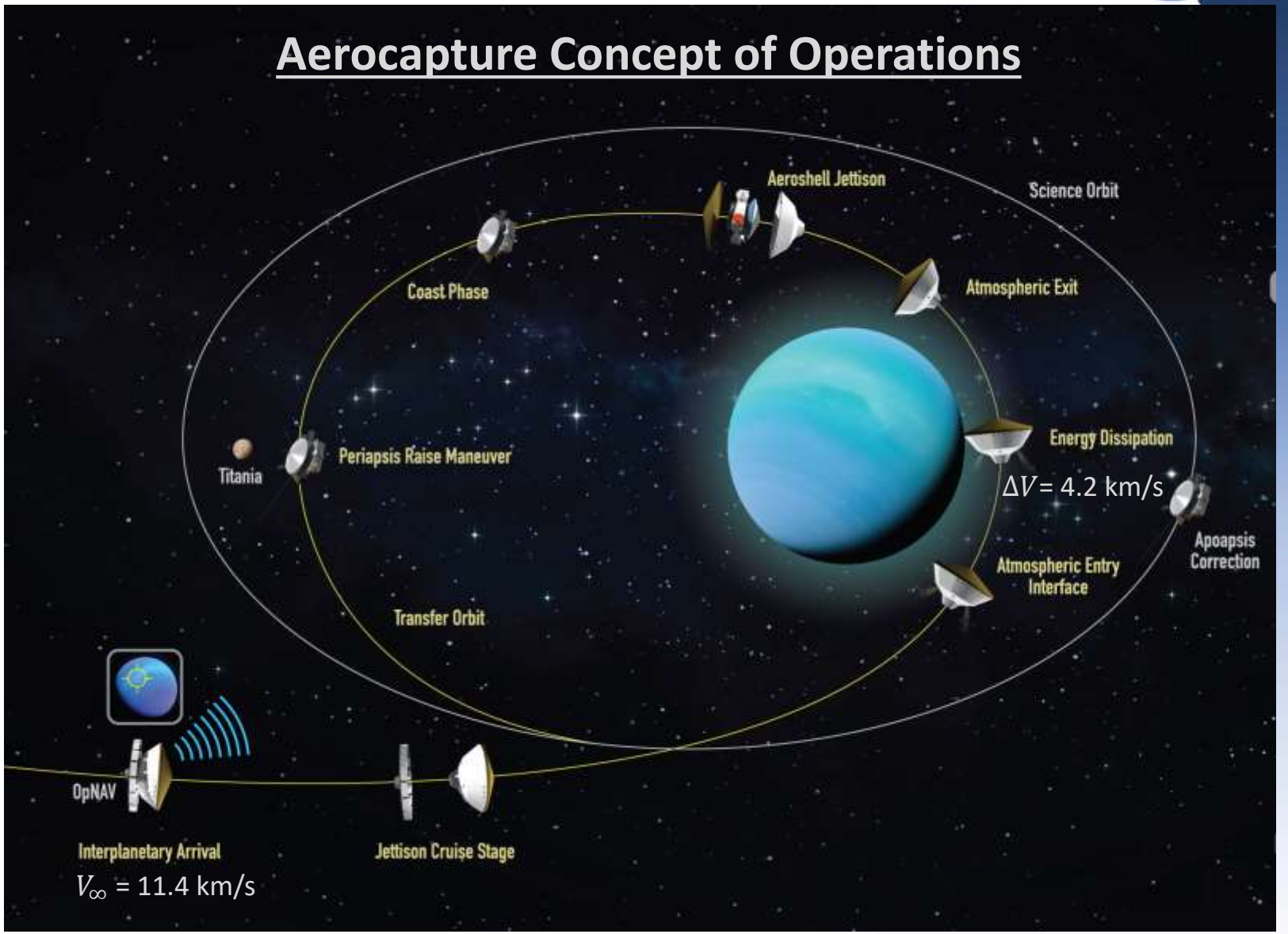
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Analytical Mechanics Associates, NASA Langley Research Center

Rohan G Deshmukh, Rafael Lugo, and Soumyo Dutta
NASA Langley Research Center



Aerocapture

- Aerocapture is a maneuver to capture into an orbit around a planet using its atmosphere to dissipate excess energy in a single pass
- Aerocapture can allow faster interplanetary trajectories and higher payloads than a fully propulsion orbit insertion
- An aerocapture at Uranus can increase the interplanetary mission design flexibility



Why Uranus?

- **2023-2032 National Academies Planetary Science and Astrobiology Decadal Survey identified the Uranus Orbiter and Probe (UOP) as the highest priority new flagship mission**

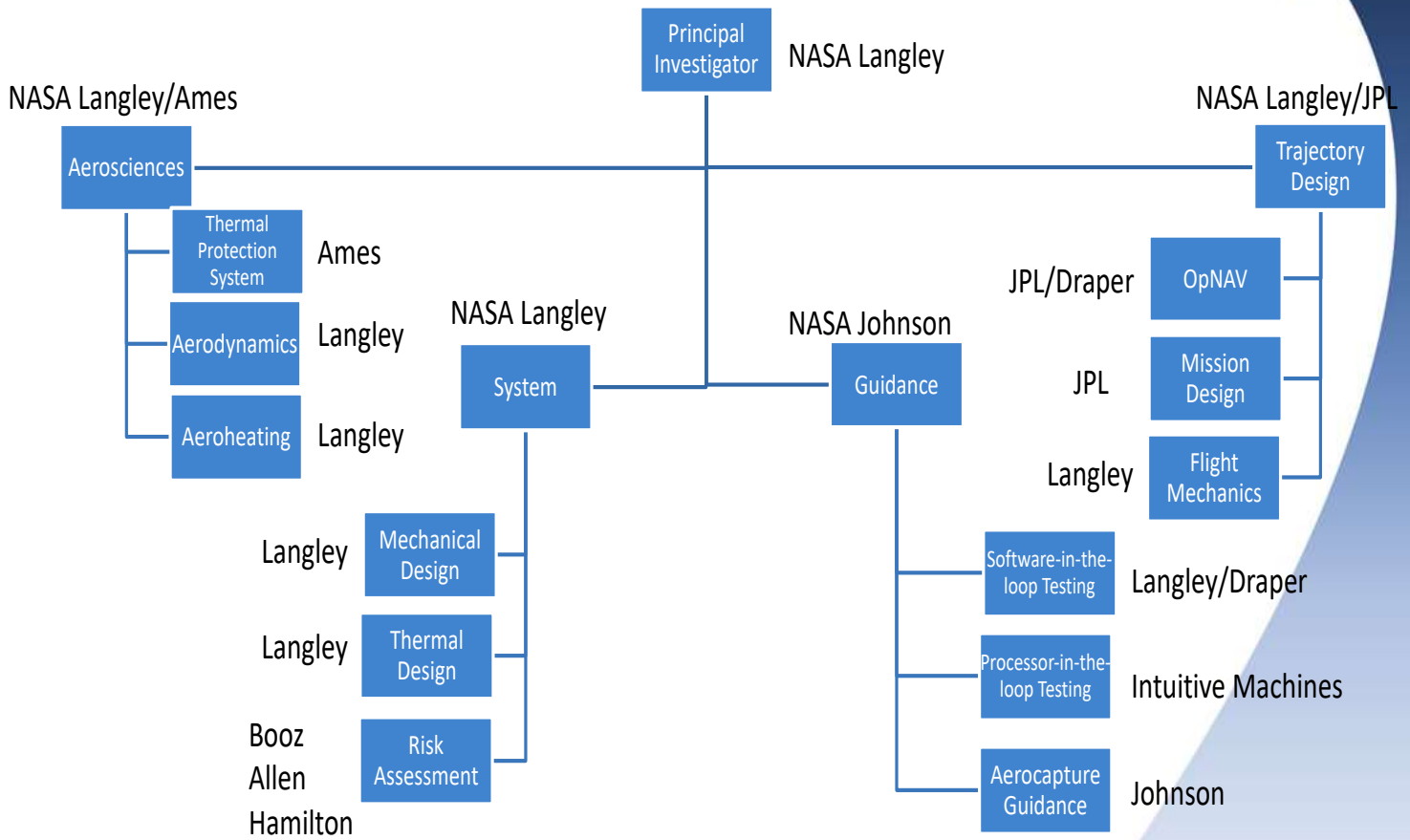
- **The baseline UOP design considers fully propulsion orbit insertion around Uranus.**
  - 13-15 years interplanetary cruise with a 2031-2032 launch window
  - Requires a Jupiter fly-by (diminishing window past 2032)*
  - High Uranus orbit insertion fuel requirements (more than 50% of wet mass)



As mentioned in talk by Declan Mages

Low Innovative Aerocapture Design

- Our aerocapture design criteria is to have a low-innovative design using heritage technologies
- Most aerocapture studies in literature consider 3-Degrees Of Freedom (DOF) trajectory analysis
- 6DOF analysis with onboard navigation errors shows that one can perform an aerocapture at Uranus using heritage technologies



See poster by Rohan Deshmukh

Heritage Technologies For Aerocapture

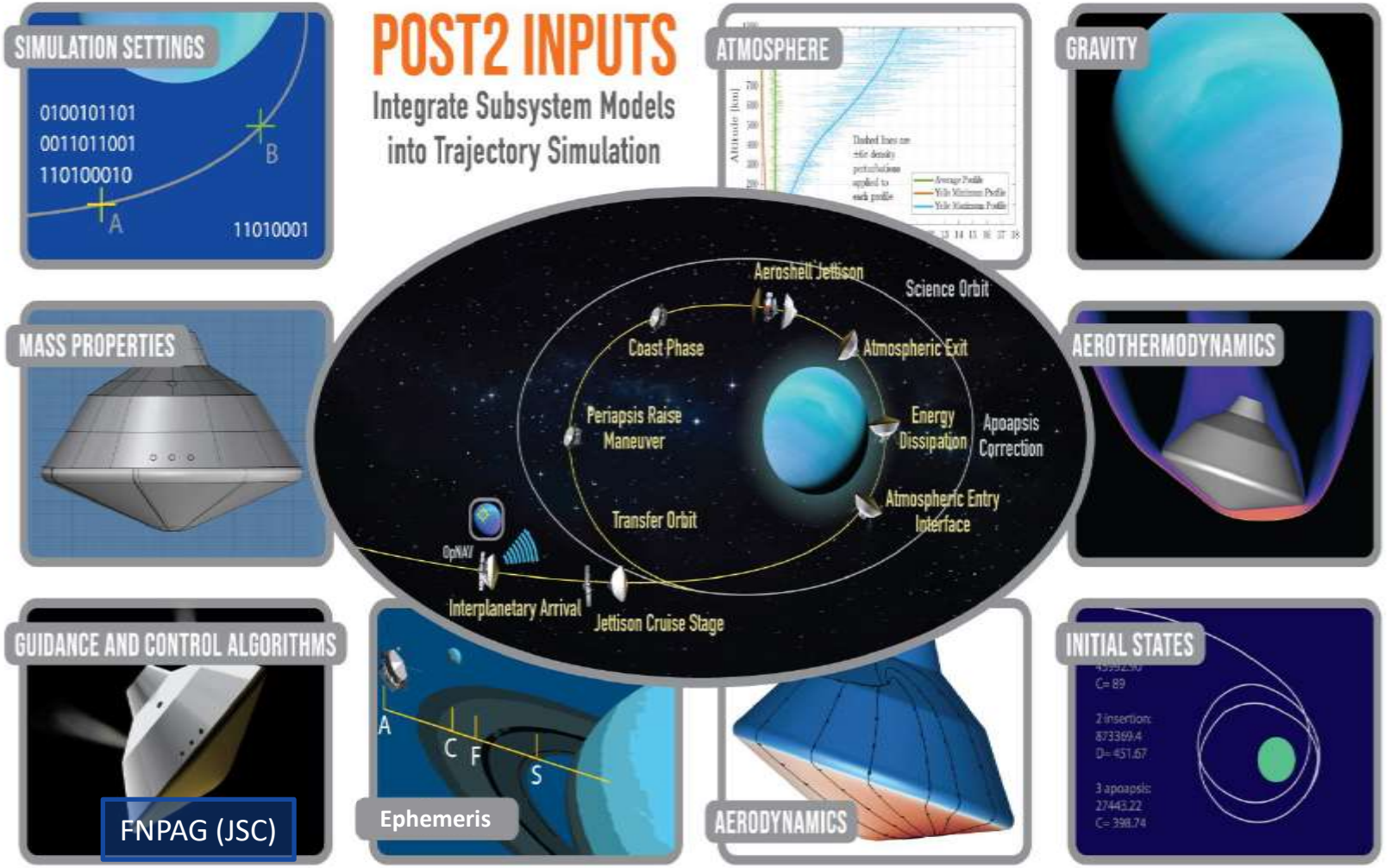
- **Aeroshell Design**
  - Mass properties and aerodynamics similar to MSL and Mars 2020
- **OpNav**
  - Used for multiple missions such as Cassini.
- **IMU**
  - Similar to the one used onboard Orion
- **Guidance**
  - FNPAG a numerical-predictor corrector guidance similar to PredGuid+A that has flown on Orion
- **Control**
  - PD controllers and RCS thrusters similar to MSL and Mars 2020



- MSL : Mars Science Laboratory
- OpNav : Optical Navigation
- PD : Proportional Derivative
- RCS : Reaction Control System

Aerocapture Simulation Setup

- **Atmosphere**
  - Uranus GRAM
  - Custom Atmosphere Model (CAM) from atmospheric scientists updated with latest measurements
- **Gravity Model**
  - Uranus oblateness modelled using J2 term
- **Aerothermodynamics**
  - For Uranus atmosphere that has mostly Hydrogen and Helium
- **Aerodynamics**
  - Aeroshell with L/D of 0.25
- **Mass Properties**
  - 4.57 m diameter with Maximum Projected Value (MPV) mass of 4064 kg



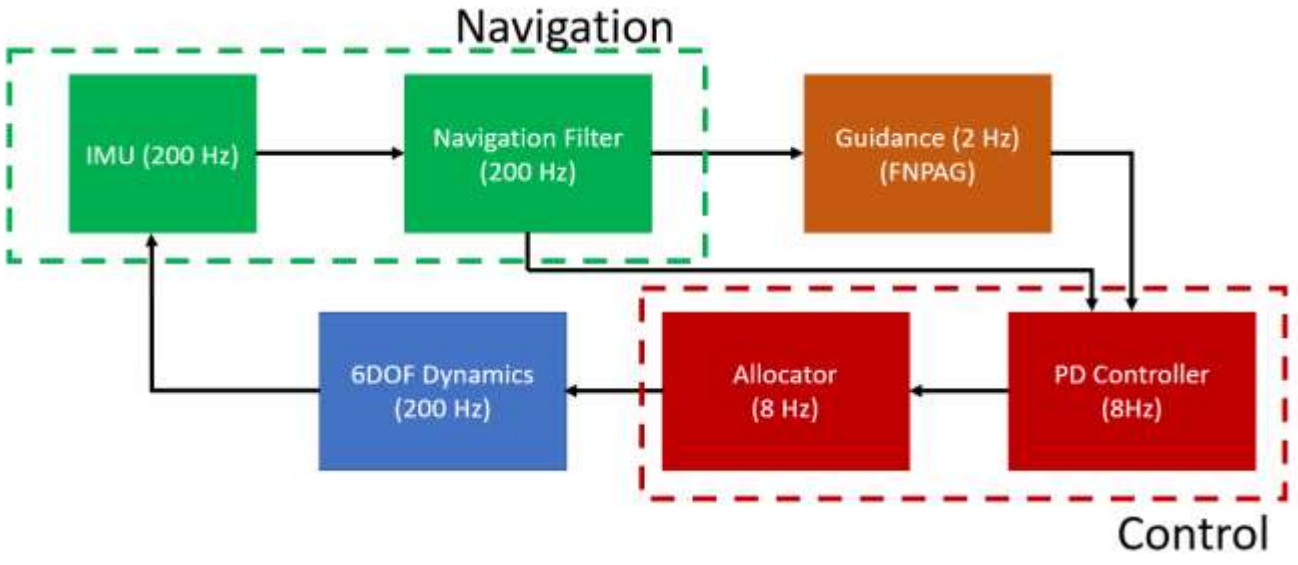
- FNPAG : Fully Numerical Predictor Aerocapture Guidance
- POST2 : Program to Optimize Simulated Trajectories II
- LaRC : Langley Research Center
- JSC : Johnson Space Center

6DOF Aerocapture Simulation Setup

- **6DOF analysis of aerocapture is not prevalent in literature**

- IMU : Inertial Measurement Unit
- PD : Proportional Derivative

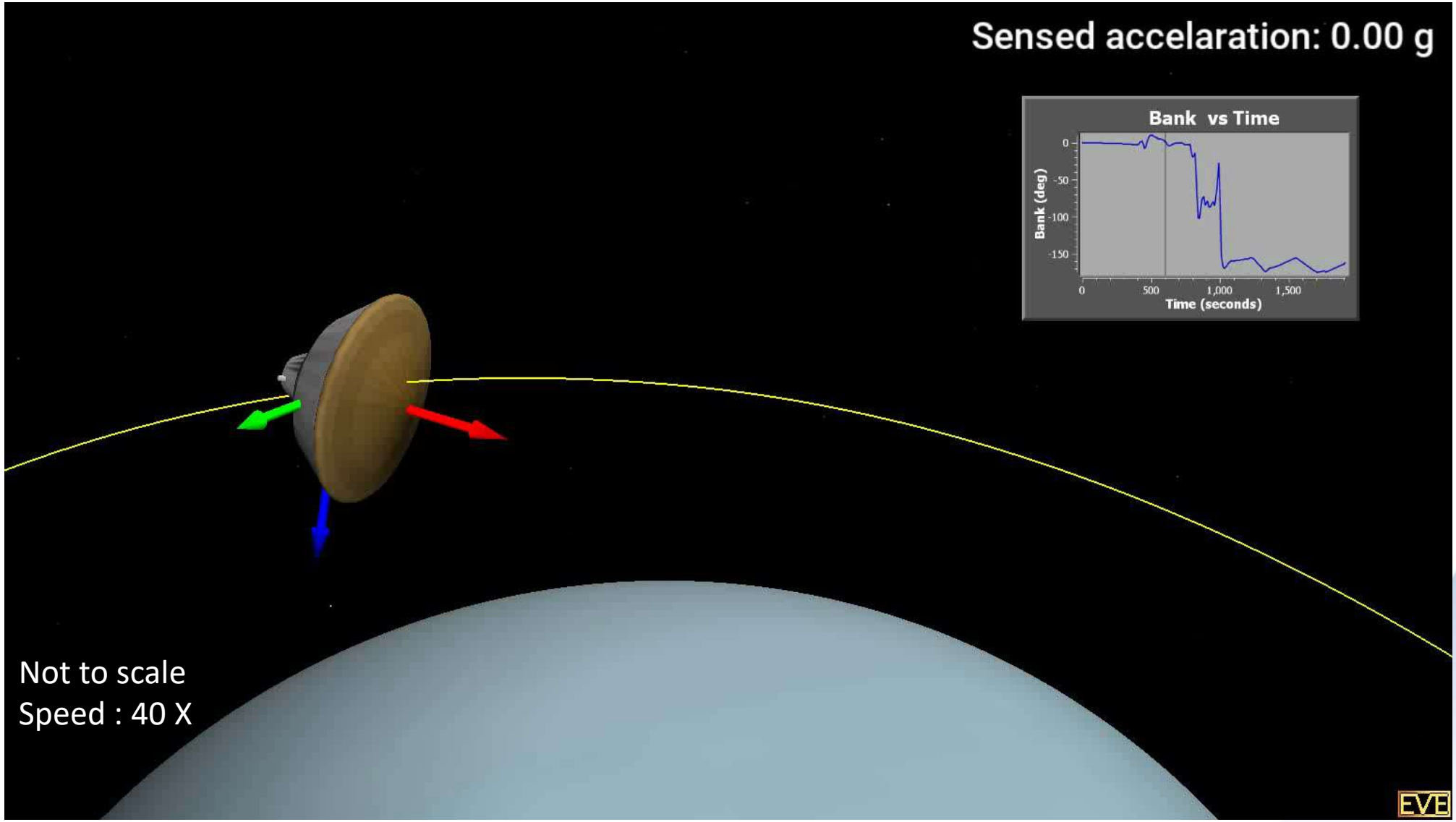
- **6DOF analysis of aerocapture relies heavily on the Guidance, Navigation and Control (GNC) subsystems**



- **The simulation ran GNC subsystems used to simulate previous EDL missions at heritage frequencies**

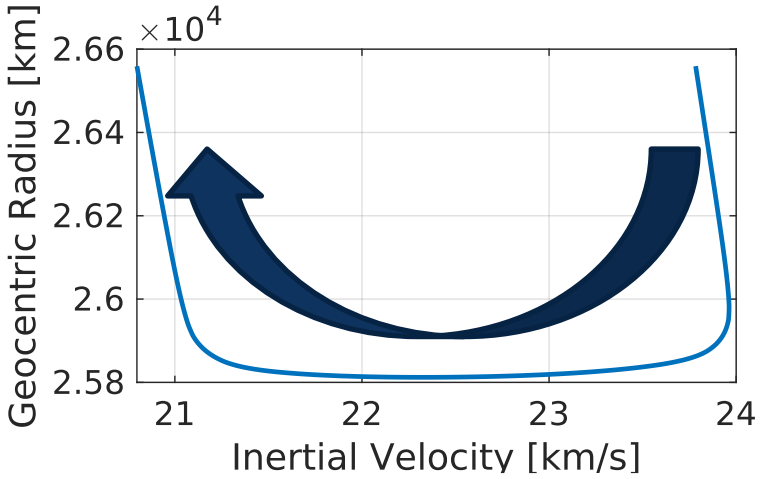
- **Major Assumptions:**
  - The center of gravity location remains unchanged due to the RCS propellant usage
  - The attitude knowledge and IMU quantization errors are currently not modelled
  - The thrust rise and fall instantaneously

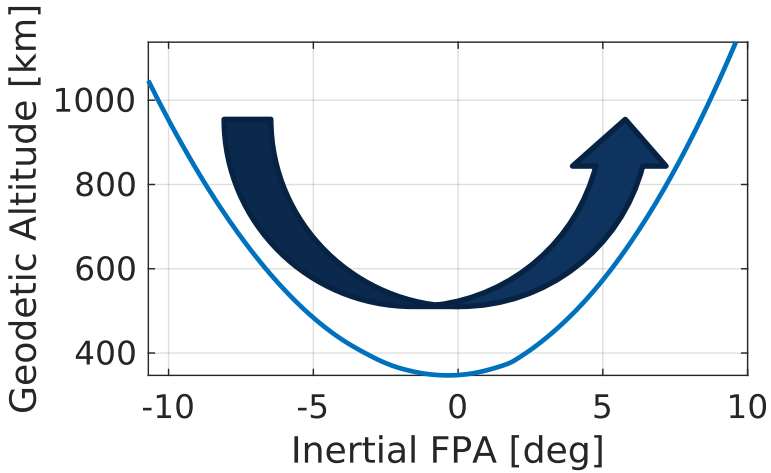
Aerocapture Visualization

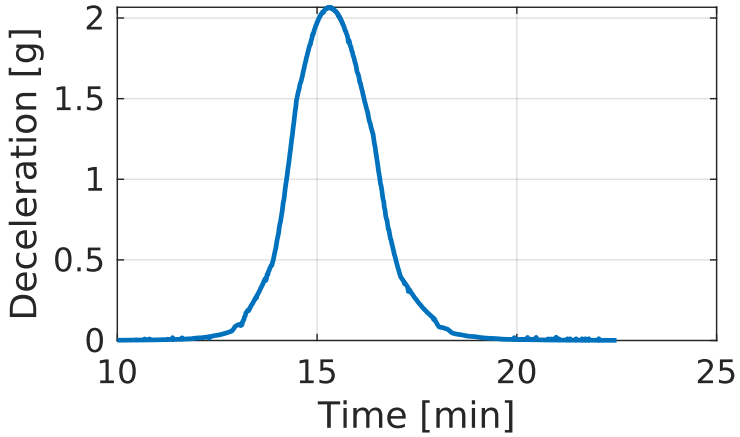


Reference Trajectory

- **Produced from 6DOF simulation using models mentioned in the simulation setup**





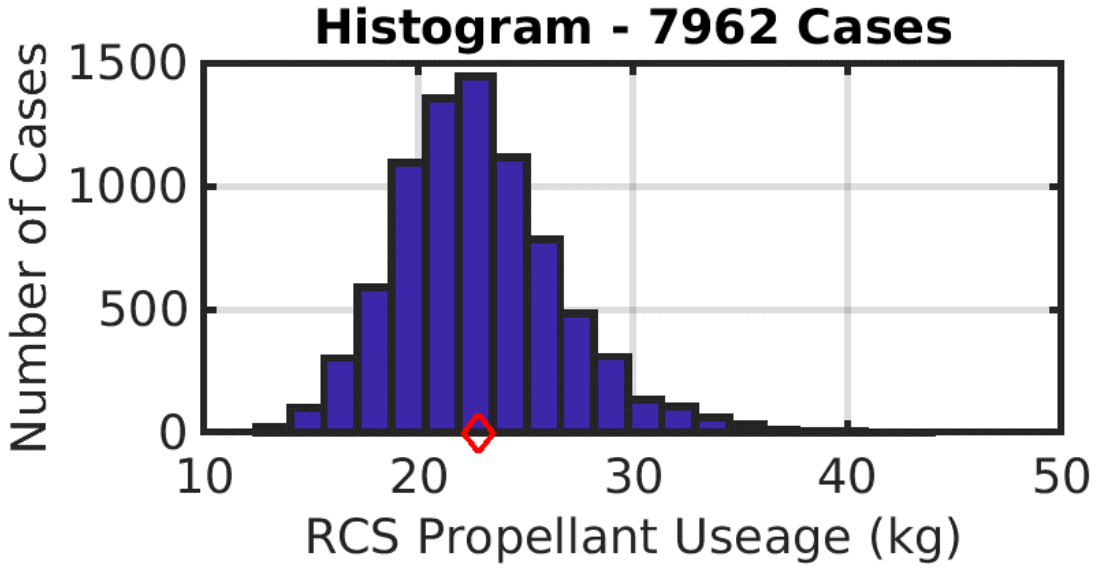


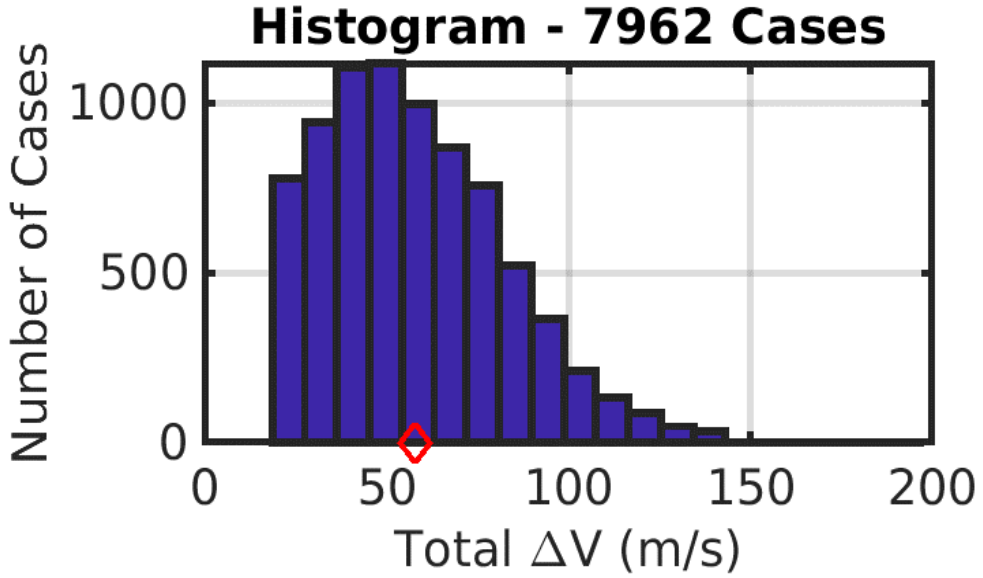
- **The Thermal Protection System (TPS) solution is C-PICA**

Please see the paper for more details on the aero heating environment of aerocapture systems for Uranus Orbiters

Baseline Monte Carlo Result

- **Capture success rate of >99.5%**
  - Uncaptured cases are all hyperbolic not landers
- **Fuel use for bank modulation maneuvers during aerocapture required is less than 34 kg (99 %-tile)**
- **Total ΔV cost for post-aerocapture burns is less than 127 m/s (99 %-tile)**
  - 5.6% of the post aerocapture mass





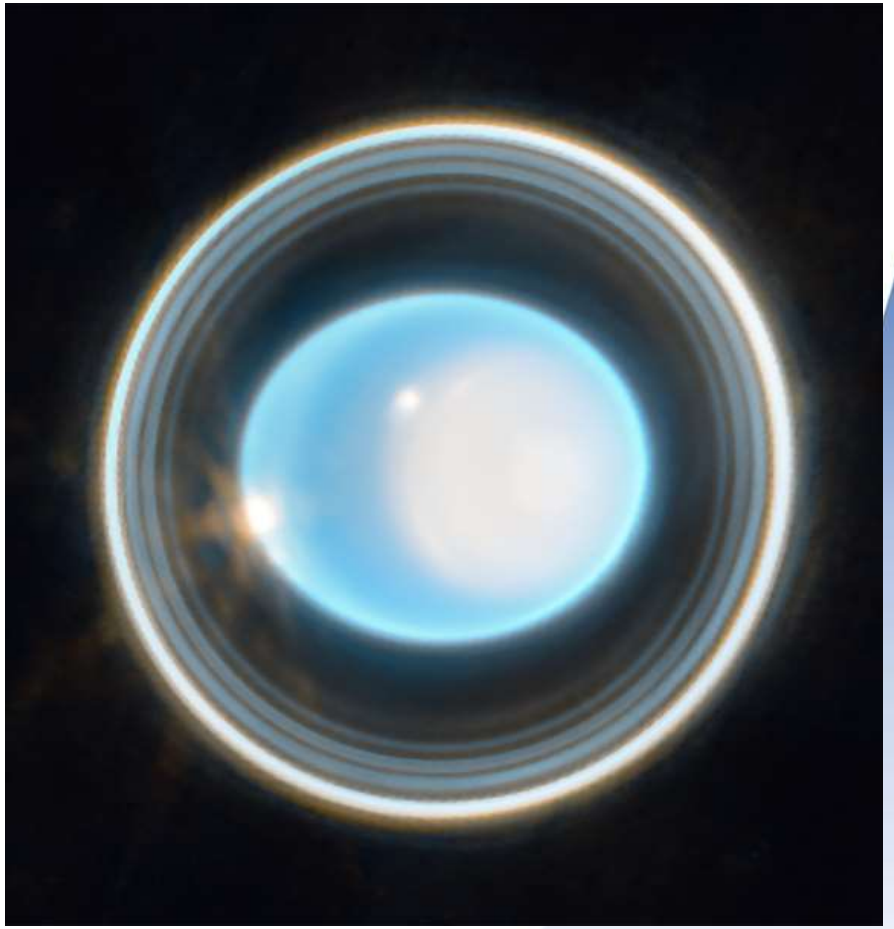
Statistics for Total ΔV (m/s):

Nominal	=	57.6583
Mean	=	57.9079
3-Sigma	=	73.992
Minimum	=	18.6693
1.00 %-tile	=	19.555
5.00 %-tile	=	23.0128
10.00 %-tile	=	27.8503
50.00 %-tile	=	54.6951
90.00 %-tile	=	91.6561
95.00 %-tile	=	103.0337
99.00 %-tile	=	126.1197
Maximum	=	196.6165

Concluding Remarks

- **Using aerocapture to capture into an orbit around Uranus offers much flexibility in the mission design**
  - Launch window has a wider range even without Jupiter flyby
  - Allows faster interplanetary trajectories without increasing the fuel requirements
  - Allows to carry more science payload

- **The 6DOF aerocapture analysis shows robustness to atmospheric, aerodynamic, navigation, and mass properties uncertainties**
  - >99.5% capture success rate
  - Aerocapture is feasible with heritage technologies



Questions

Talk by Declan Mages	
Poster by Rohan Deshmukh	
Paper on aero heating environment	

