AURORA

Aerocapture **U**ranus p**R**obe & **O**rbiter for **R**econnaissance & **A**nalysis

Team 8 - Julianne,
Jace, Tamara, Cynthia

Introductions - Team 8

Julianne Miana
Mission Ops & Scientific Instrumentation

Jace Lu
Mission Ops & Trajectory Planning

Cynthia Cao
Scientific & Technical Motivation

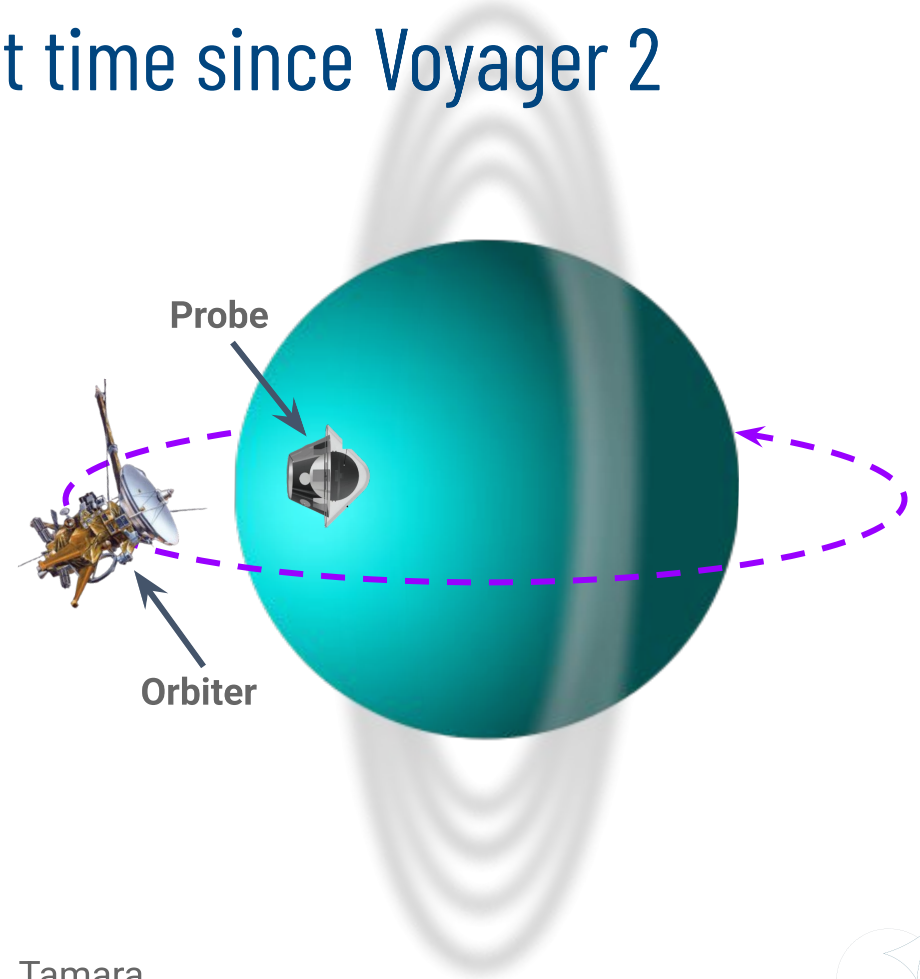
Tamara Hinderman
Pitch Team Lead & Technical Motivation

Contributors: Tamara
Presenting: Tamara

Revisiting Uranus for the first time since Voyager 2

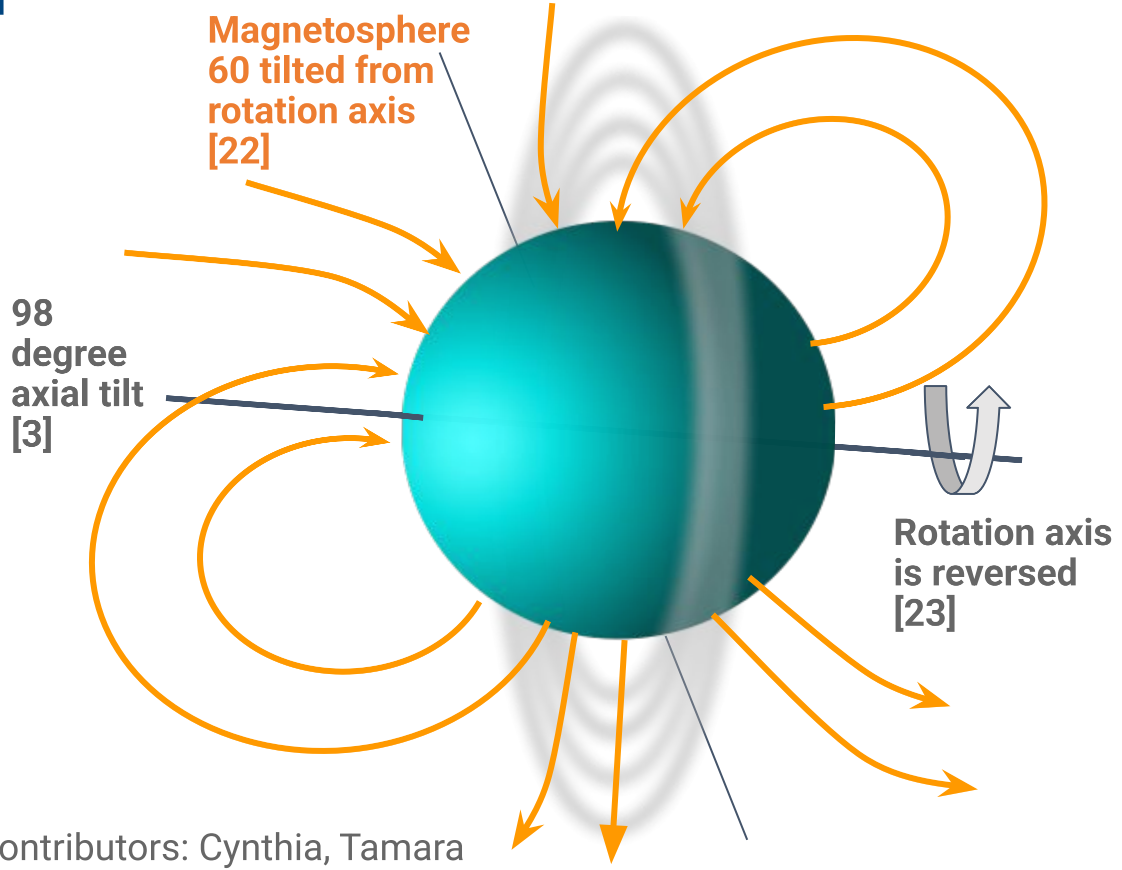
AURORA:

- Sending an orbiter and probe to Uranus to investigate
  - planet's properties
  - atmospheric conditions
  - exoplanet origins
- Last time: Voyager 2 flyby (1986)
- 1st orbiter & probe reconnaissance mission



Contributors: Julianne, Jace, Cynthia, Tamara
Presenting: Tamara

Researching Planetary Formation Through Tilt & Magnetosphere

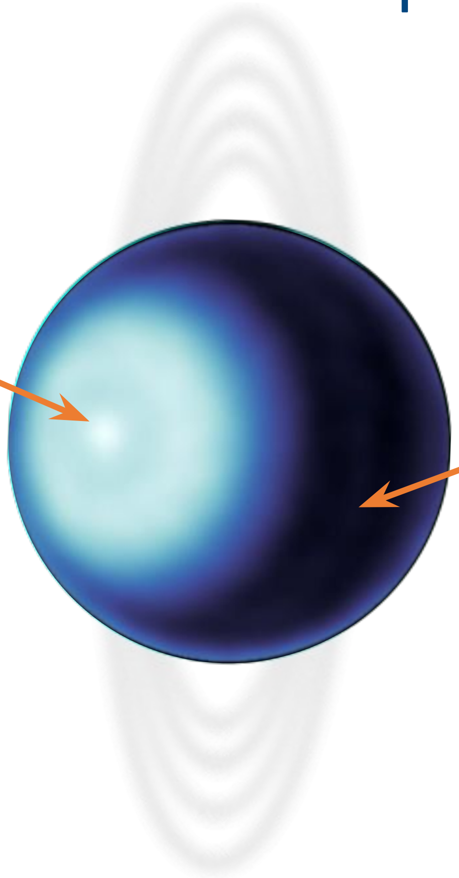


Contributors: Cynthia, Tamara
Presenting: Cynthia

Investigating Uranus' Extreme Atmospheric Conditions

Coldest atmosphere in solar system:
-320 F
-196 C

Little understanding of heat flux and internal heat [14]



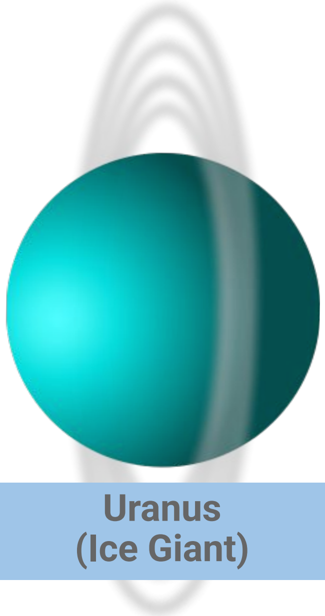
Unclear atmospheric circulation from interior to thermosphere [14]

Leveraging Uranus to Explore Exoplanet Origins

TOI-421 b
(Hot Sub-Neptune)

GJ 1214 b
(Warm Sub-Neptune)

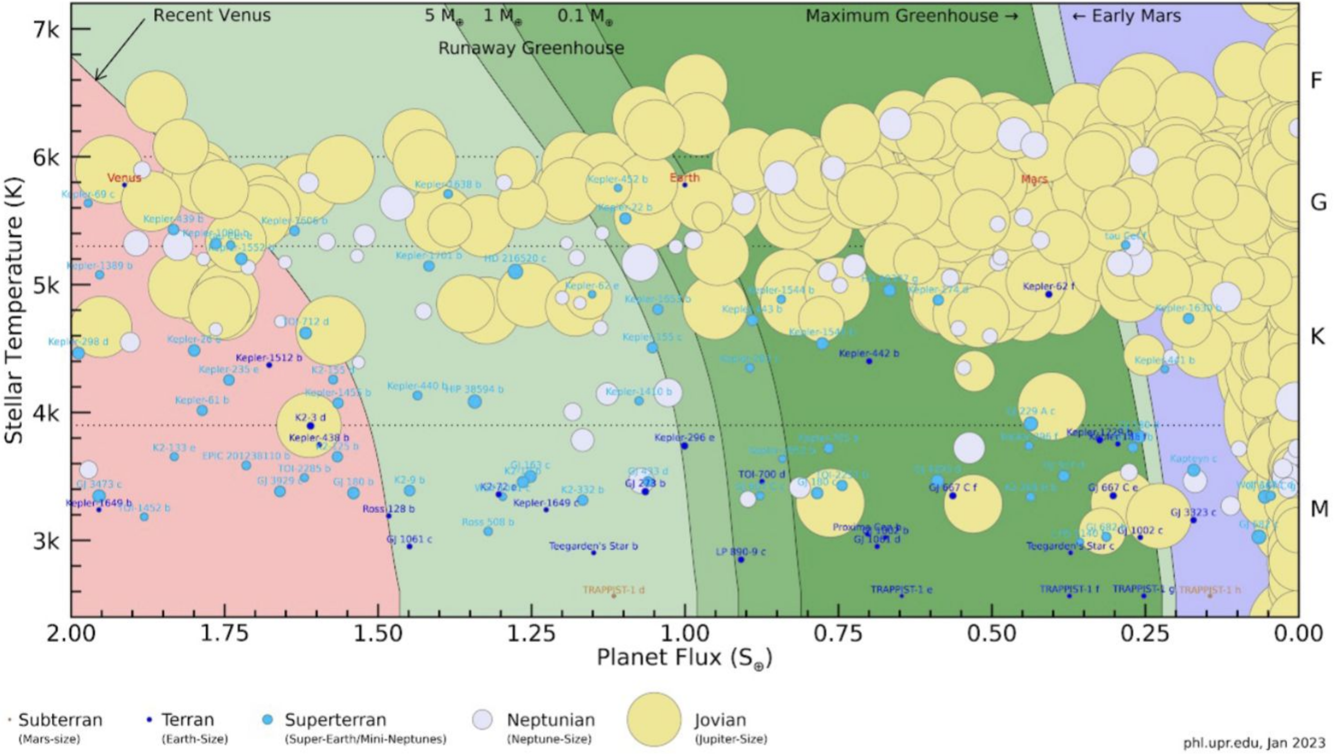
Neptune
(Ice Giant)



Uranus
(Ice Giant)

Contributors: Cynthia, Tamara
Presenting: Cynthia

Leveraging Uranus to Explore Exoplanet Origins



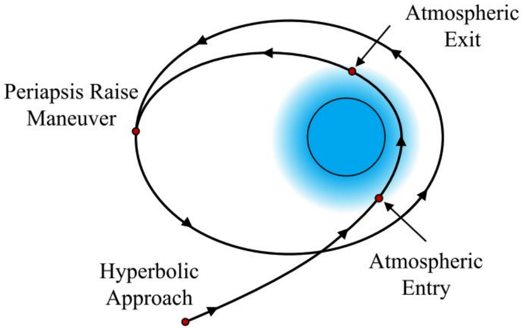
Contributors: Cynthia, Tamara
Presenting: Cynthia

Why AURORA?

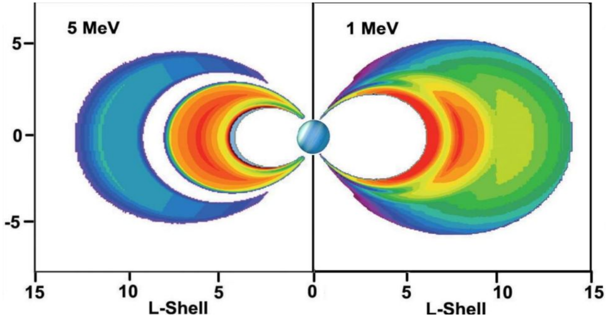
Testing novel concepts for novel problems

- Using aerocapture for the first time at an outer planet to decelerate into stable orbit [1][9][12][16]

- Designing spacecraft to handle extreme conditions
  - Orbit/tilt around Uranus [23]
  - Magnetic field + radiation [11][22]
  - Extreme temperatures + winds [14][16]



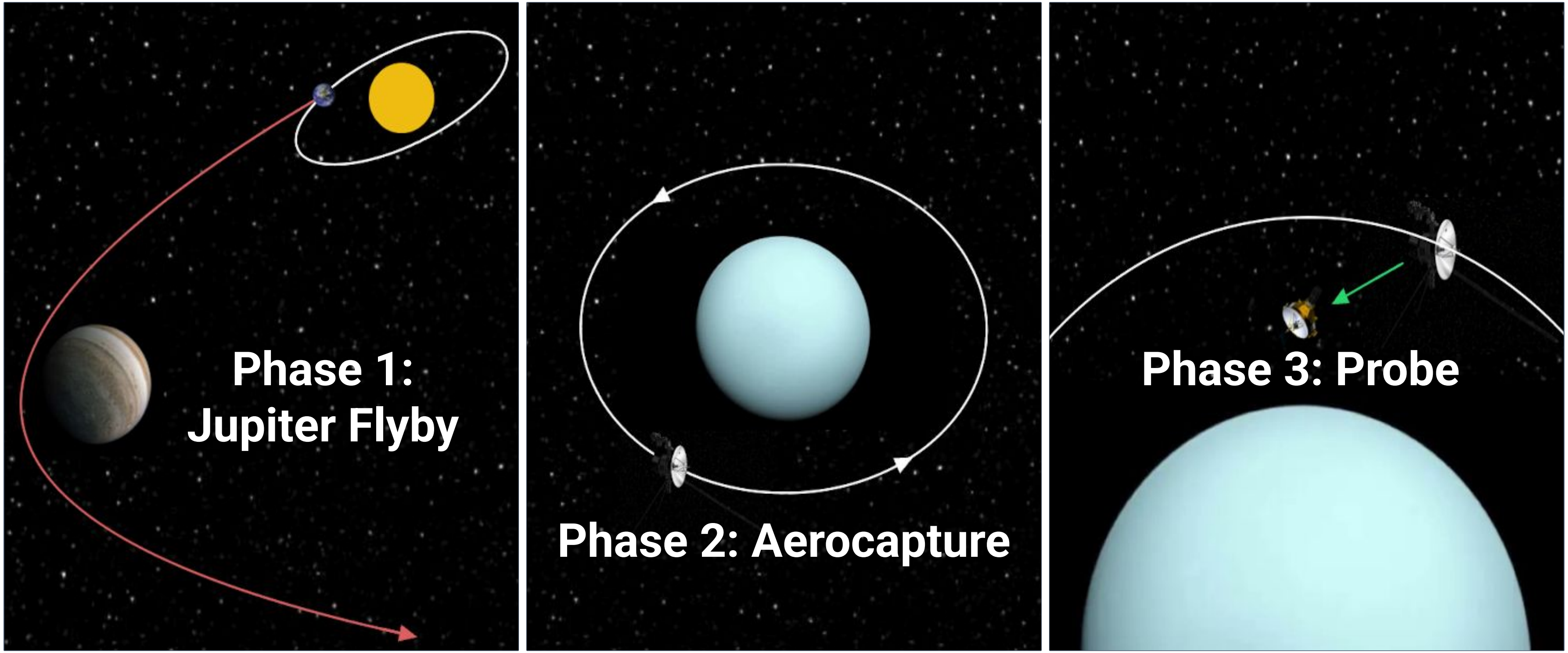
Aerocapture Diagram [12]



Uranian Radiation Belt Model [11]

Contributors: Tamara, Cynthia, Julianne
Presenting: Tamara

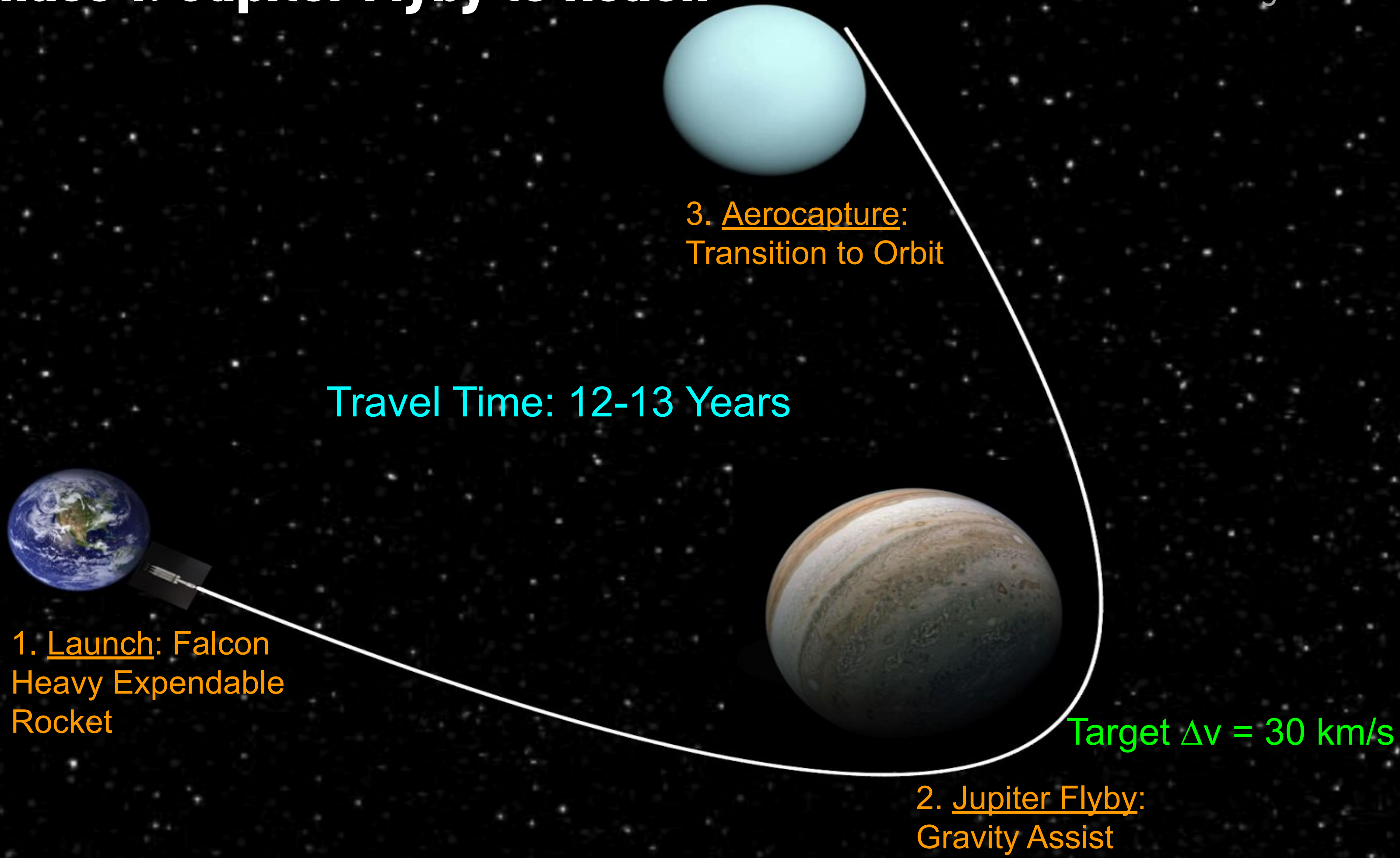
Conops



Contributors: Julianne, Jace, Cynthia, Tamara
Presenting: Tamara

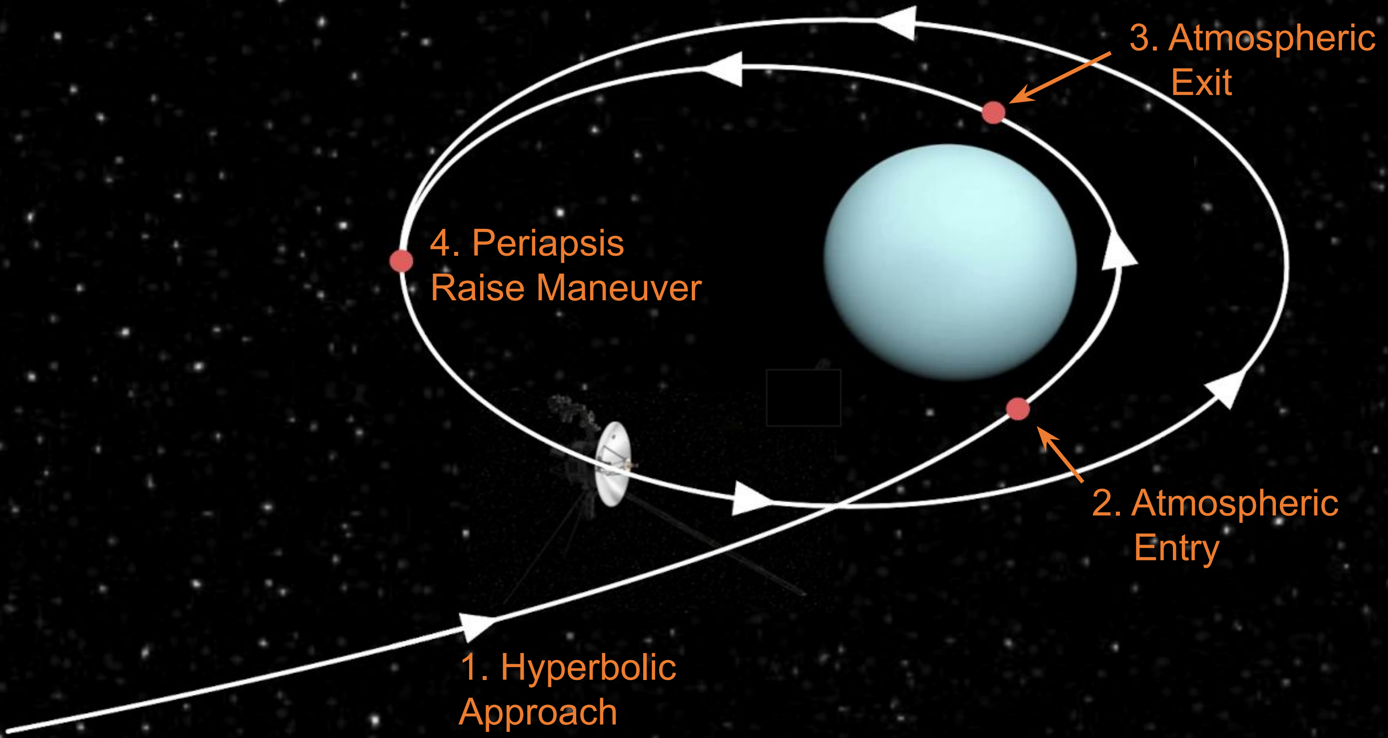
CONOPS Phase 1: Jupiter Flyby to Reach Uranus

Contributors: Jace
Presenting: Jace



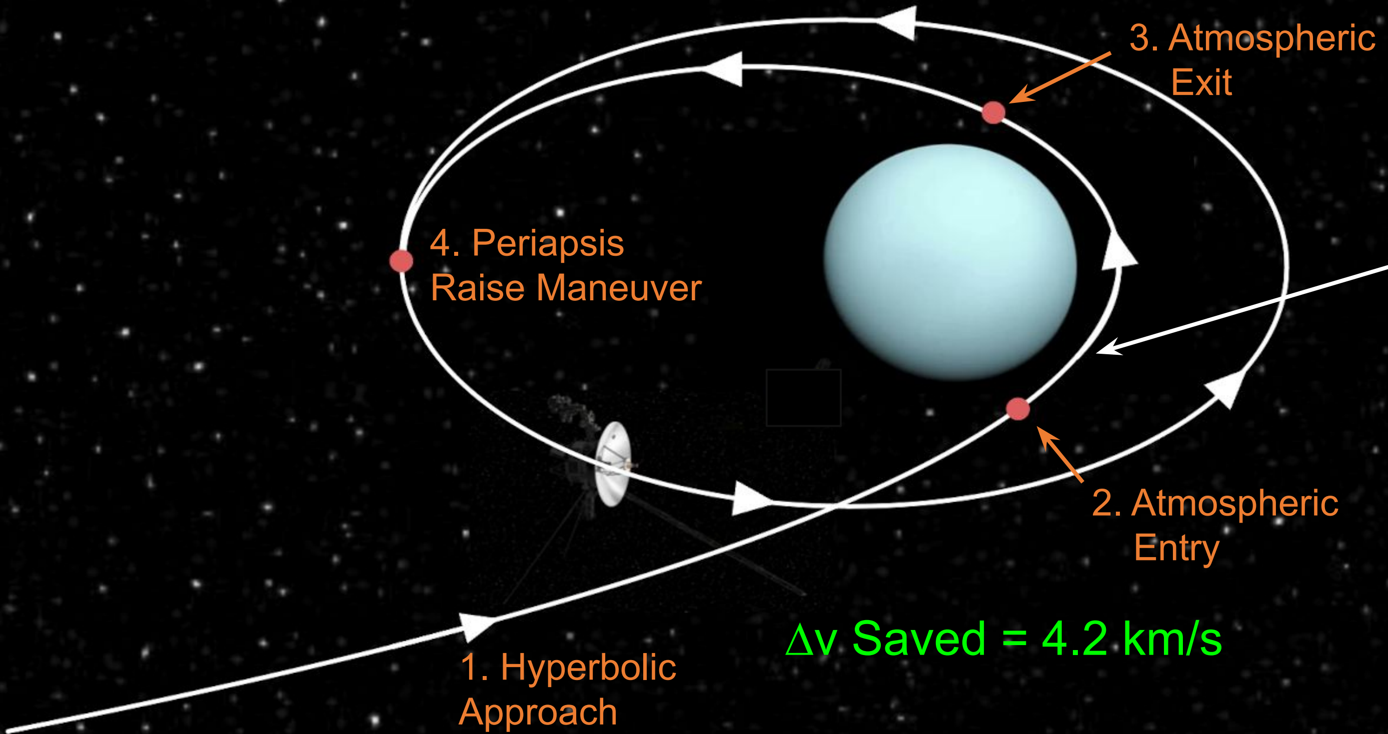
CONOPS Phase 2: Aerocapture to Transition to Orbit

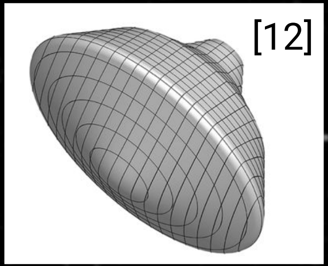
Contributors: Jace
Presenting: Jace



CONOPS Phase 2: Aerocapture to Transition to Orbit

Contributors: Jace
Presenting: Jace

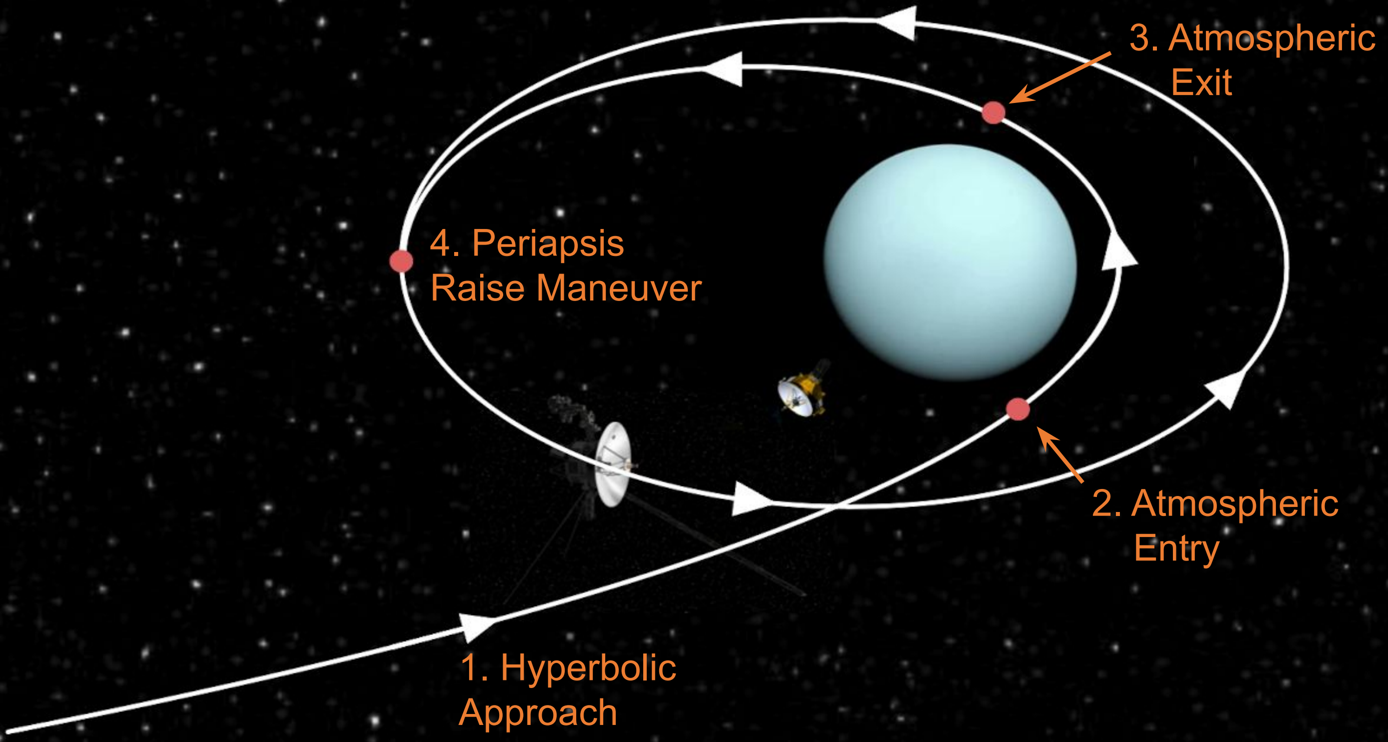




Blunt Body: L/D = 0.25
Altitude: 1000km
Entry Velocity: 23.78km/s
HEET/other TPS Material

CONOPS Phase 3: Launching Probe to Collect Data

Contributors: Jace
Presenting: Jace



CONOPS Phase 3: Launching Probe to Collect Data

Contributors: Jace
Presenting: Julianne

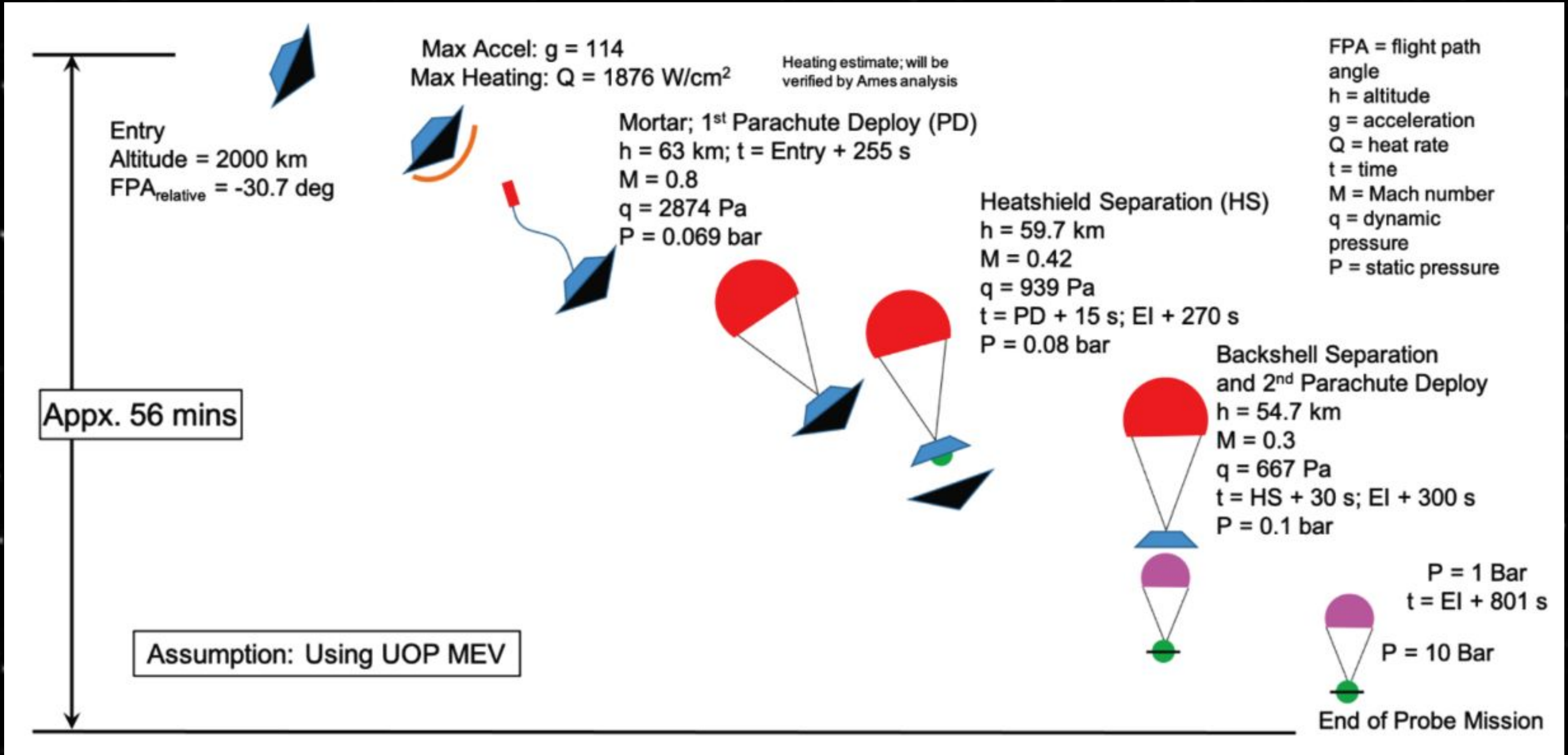
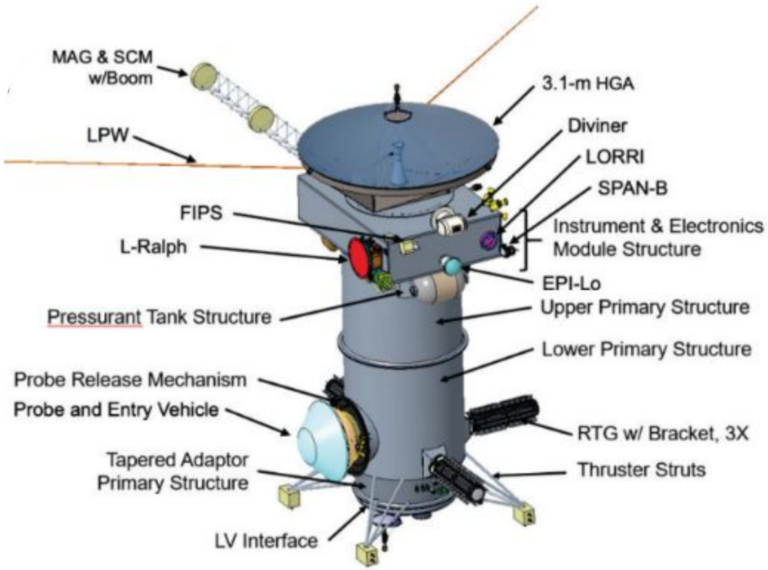


Exhibit 3-34. *Probe Trajectory Concept of Operations.*

2021 NASA Uranus Orbiter & Probe Mission Concept Study [7]

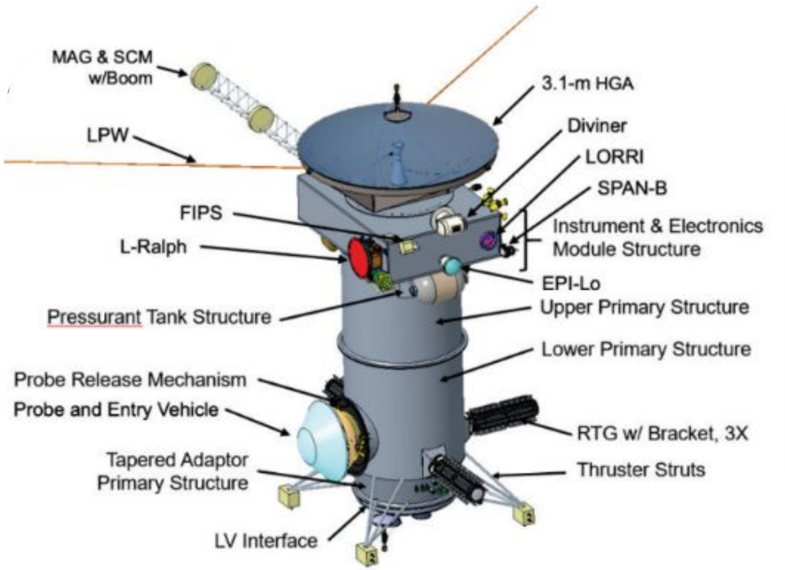
Utilizing existing orbiter technology



2021 NASA Uranus Orbiter & Probe Mission Concept Study [7]

- Imaging [7]
  - Thermal IR Camera: **characterize thermal environment** (LRO Diviner)
  - Magnetometer + Boom: **measure magnetic field** (MESSENGER, Cassini)
- Scientific analysis [7]
  - Fields & particles package:
    - EPI-Lo: **characterize energetic particles** (Solar Parker Probe)

Utilizing existing orbiter technology



2021 NASA Uranus Orbiter & Probe Mission Concept Study [7]

- Thermal / Material [7][10]
  - HEEET TPS
  - Anodized Al shielding
- Comms [7]
  - Radio Science Experiment (MESSENGER / RS)
- Power
  - RTGs

Combining existing and proposed probe technologies

- Scientific Payload: [7]
    - Atmospheric Structure Instrument: **measure properties of atmosphere** (Cassini-Huygens)
    - Mass Spectrometer: **identify unknown compounds** (Rosetta DFMS)
    - Ortho-Para Instrument: **detect and measure hydrogen isomer ratio**
- Thermal
    - Single-layer HEEET TPS
- Power
    - 2 lithium batteries

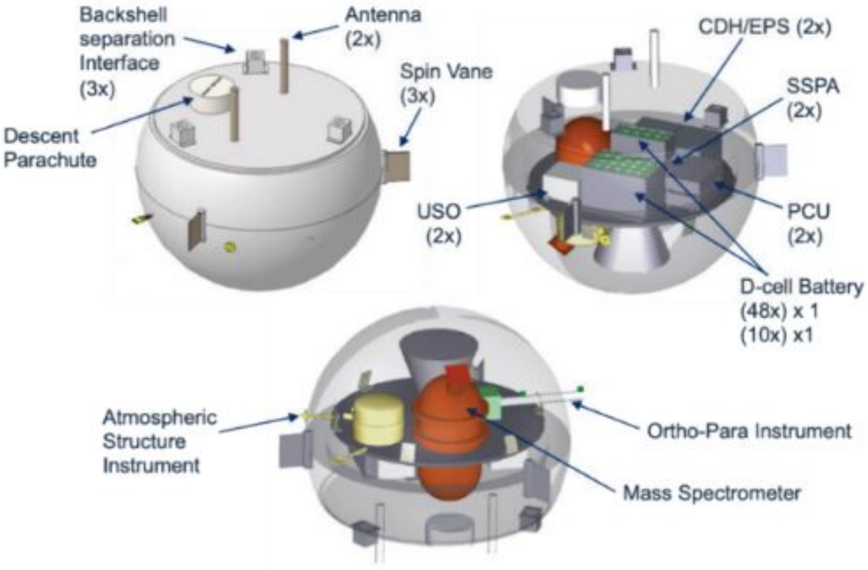
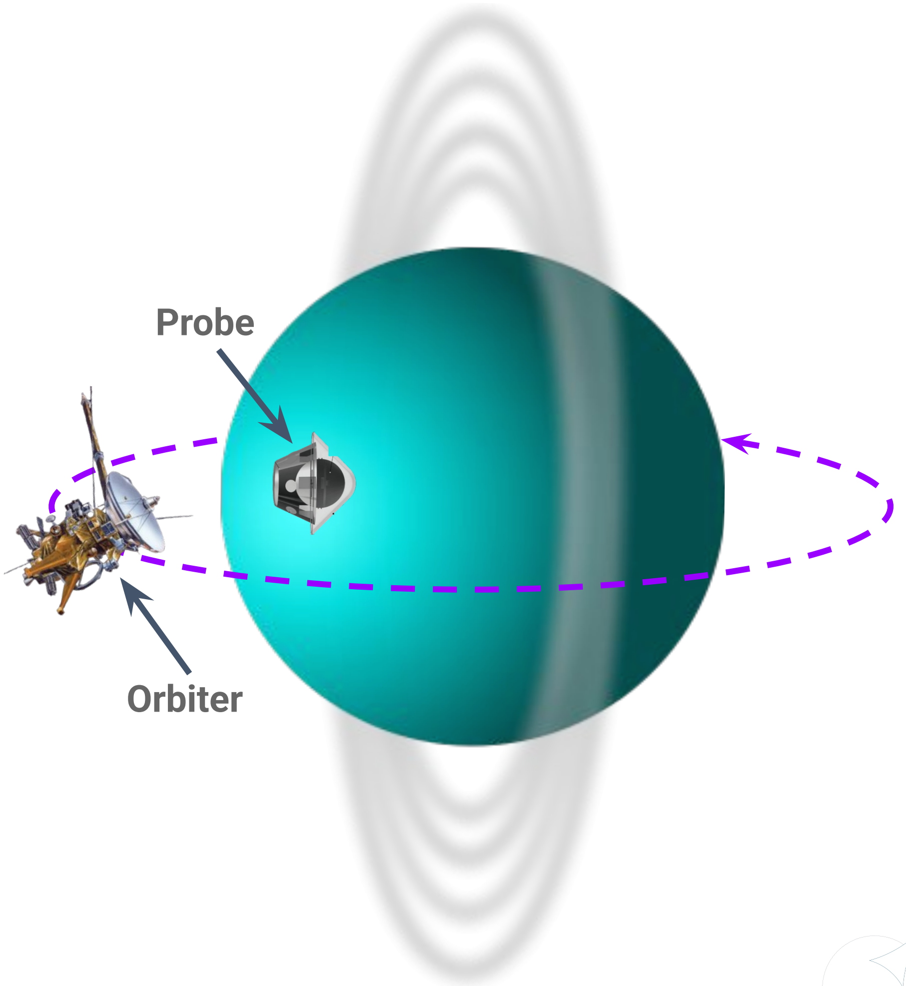


Exhibit 3-19. Descent module configuration.

2021 NASA Uranus Orbiter & Probe Mission Concept Study [7]

AURORA Mission Value

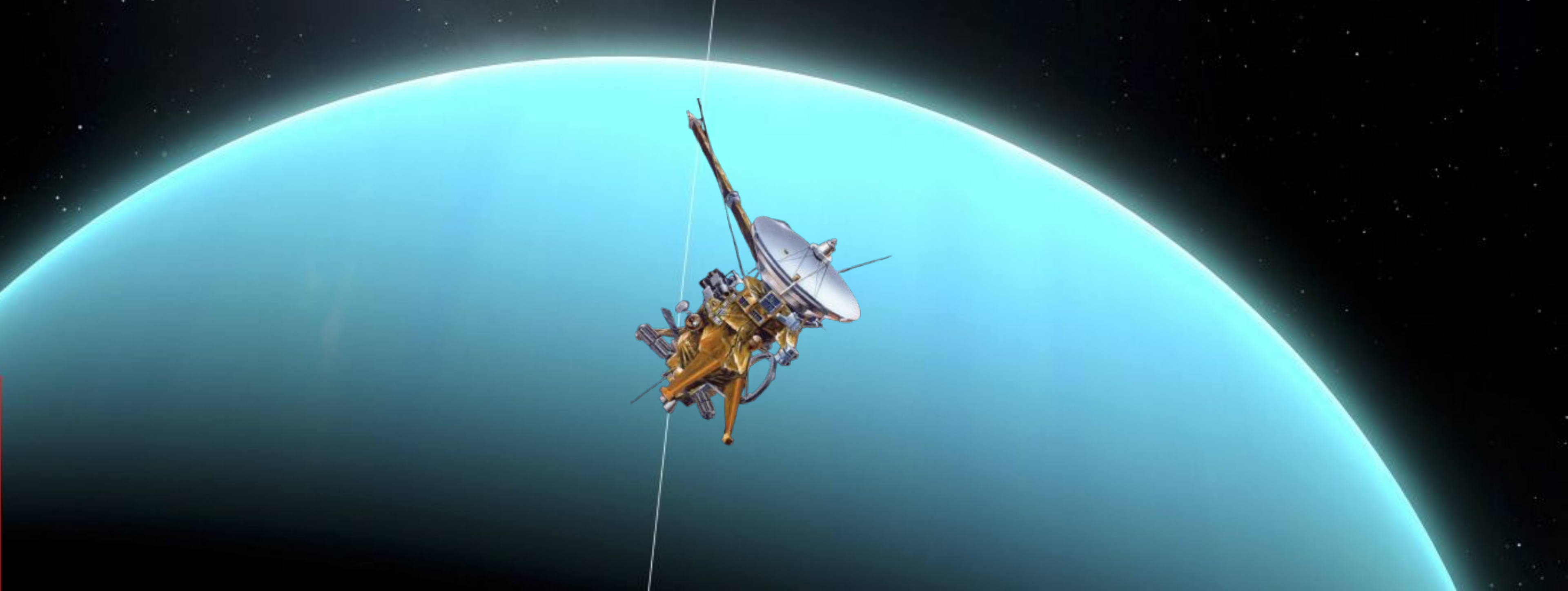
- First orbiter and probe for investigating Uranus
- Fulfills multiple scientifically valuable objectives
- Challenging design environment
- Innovating on flight heritage technology to solve a novel problem

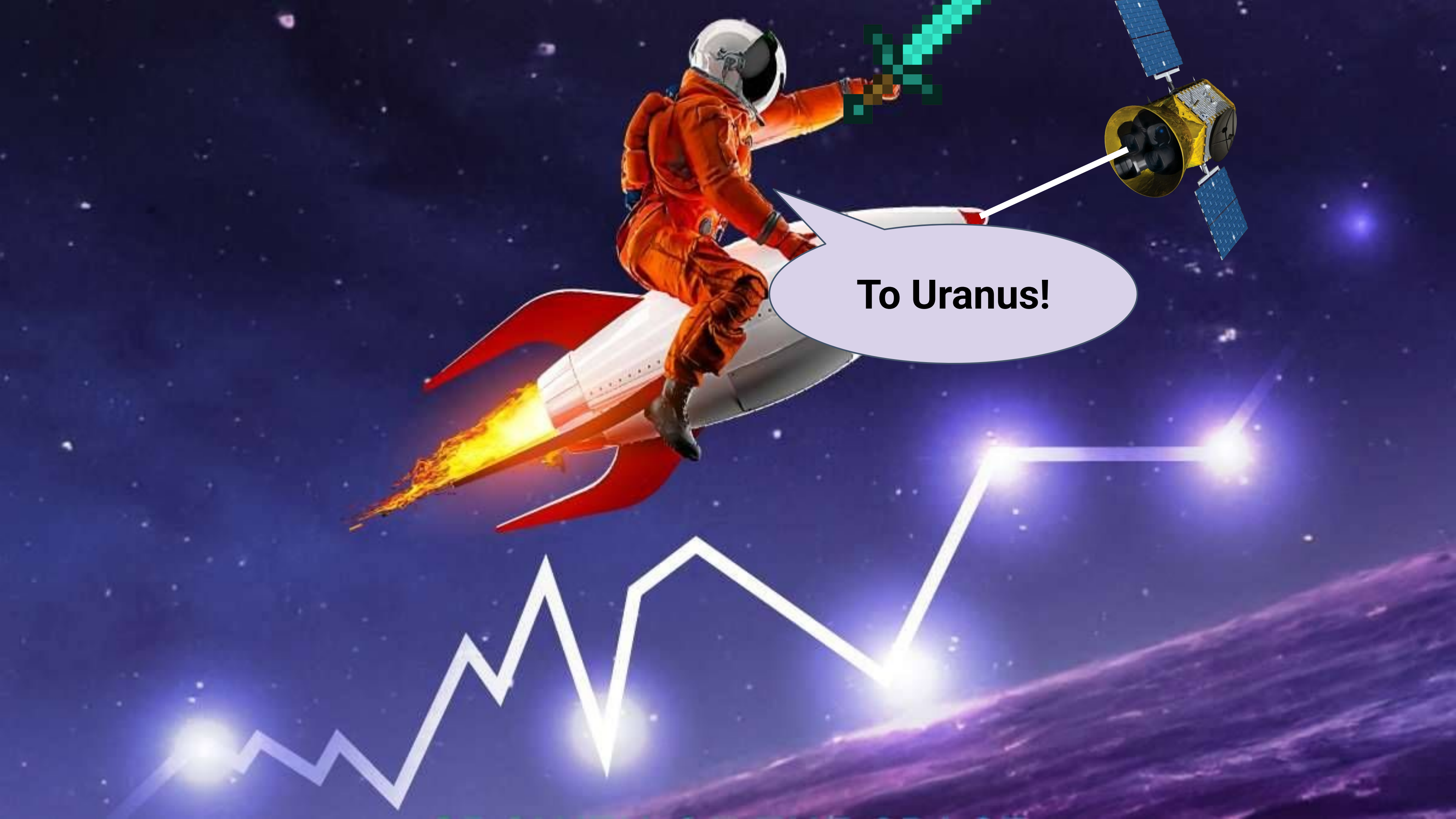


MIT AEROASTRO Contributors: Tamara
Presenting: Tamara

AURORA

Together we can explore the depths of Uranus!




To Uranus!

Bibliography

[1] Agrawal et. al., "Atmospheric Entry Studies for Uranus" 2014 IEEE Aerospace conference, Big Sky Montana. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.hou.usra.edu/meetings/icegiants2014/presentations/Day_3/Agrawal_2008.pdf

[2] Astrobites. "Why Are There so Many Sub-Neptune Exoplanets?" AAS Nova, 28 Aug. 2024, aasnova.org/2020/02/04/why-are-there-so-many-sub-neptune-exoplanets/. Accessed 05 Mar. 2025.

[3] "Axial Tilt." Wikipedia, Wikimedia Foundation, 19 Feb. 2025, en.wikipedia.org/wiki/Axial_tilt. Accessed 05 Mar. 2025.

[4] "Babbage: The Hunt for New Worlds: Babbage from the Economist." Acast, shows.acast.com/theeconomistbabbage/episodes/babbage-the-hunt-for-new-worlds. Accessed 05 Mar. 2025.

[5] Blue, Charles. "Planetary Rings of Uranus 'glow' in Cold Light." National Radio Astronomy Observatory, 20 June 2019, public.nrao.edu/news/2019-alma-rings-uranus/. Accessed 05 Mar. 2025.

[6] Bridgman, Tom. "NASA Scientific Visualization Studio." NASA, 5 Jan. 2025, svs.gsfc.nasa.gov/4144/. Accessed 05 Mar. 2025.

[7] Cohen, Ian J., et al. "Uranus Orbiter and Probe (UOP): The 2023-2032 Planetary Survey and Astrobiology Decadal Survey Mission Concept." AGU Fall Meeting Abstracts. Vol. 2023. 2023. https://drive.google.com/drive/folders/1Qlun6EF0v472eOMXXokHxa6B2tBLNkdv

[8] Cowing, Keith. "Exoplanet Analysis Practice Using Uranus, Hubble, and New Horizons." Astrobiology, 10 Oct. 2024, astrobiology.com/2024/10/exoplanet-analysis-practice-using-uranus-hubble-and-new-horizons.html. Accessed 05 Mar. 2025.

[9] Deshmukh, Rohan, et al. "6-DoF Uranus Aerocapture Trajectory Analysis." AIAA SCITECH 2025 Forum. 2025. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://arc.aiaa.org/doi/pdfplus/10.2514/6.2025-1510

[10] Ellerby, Donald T., and Matthew J. Gasch. "Heatshield for extreme entry environment technology (HEEET) thermal protection system (TPS)." Annual Conference on Composites, Materials, and Structures. No. ARC-E-DAA-TN72926. 2019.

[11] Garrett, Henry, Luz Maria Martinez-Sierra, and Robin Evans. The JPL Uranian radiation model (UMOD). No. JPL-Publ-15-07. 2015.

[12] Gochenaur, Daniel C., et al. "Orbit Plane Rotation Using Aerocapture." Journal of Spacecraft and Rockets (2025): 1-34.

[13] Gochenaur Daniel C, et al. "Starship as an Enabling Option for a Uranus Flagship Mission." 2025 IEEE Aerospace Conference. (unpublished MIT paper)

Bibliography

[14] Lunine, Jonathan I. (September 1993). "The Atmospheres of Uranus and Neptune". Annual Review of Astronomy and Astrophysics. 31: 217–263. Bibcode:1993ARA&A..31..217L. doi:10.1146/annurev.aa.31.090193.001245.

[15] National Research Council, et al. *Vision and voyages for planetary science in the decade 2013-2022*. National Academies Press, 2012. https://science.nasa.gov/resource/vision-and-voyages-for-planetary-science-in-the-decade-2013-2022-2/

[16] NASA. " Aerocapture for Discovery Missions- Briefing prepared for Discovery AO participants." June 2010, Microsoft PowerPoint presentation.

[17] “NASA’s James Webb Space Telescope Primed to Lift the Haze Surrounding Sub-Neptunes.” NASA, 18 Sept. 2023, www.nasa.gov/universe/nasas-james-webb-space-telescope-primed-to-lift-the-haze-surrounding-sub-neptunes/. Accessed 05 Mar. 2025.

[18] News, RNZ. “Uranus Is a Very Weird Planet. Here’s Why Astronomers Want to Probe It.” RNZ, 1 May 2022, www.rnz.co.nz/news/world/466254/uranus-is-a-very-weird-planet-here-s-why-astronomers-want-to-probe-it. Accessed 10 Mar. 2025.

[19] “Planetary Science and Astrobiology Decadal Survey 2023-2032.” Nationalacademies.Org, www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032#sectionPublications. Accessed 05 Mar. 2025.

[20]“Read ‘Origins, Worlds, and Life: Planetary Science and Astrobiology in the next Decade’ at Nap.Edu.” Uranus Orbiter and Probe | Origins, Worlds, and Life: Planetary Science and Astrobiology in the Next Decade | The National Academies Press, nap.nationalacademies.org/read/27209/chapter/8#32. Accessed 05 Mar. 2025.

[21] “The Guardian View on NASA’s Next Frontier: Exploring the Hidden Oceans of Uranus Is Worth It | Editorial.” The Guardian, Guardian News and Media, 28 Nov. 2024, www.theguardian.com/commentisfree/2024/nov/28/the-guardian-view-on-nasas-next-frontier-exploring-the-hidden-oceans-of-uranus-is-worth-it. Accessed 05 Mar. 2025.

[22] “The Magnetic Fields of Uranus and Neptune.” The Planetary Society, www.planetary.org/space-images/the-magnetic-fields-of-uranus-and-neptune. Accessed 05 Mar. 2025.

[23] “Uranus - NASA Science.” NASA, 5 June 2023, science.nasa.gov/gallery/uranus/. Accessed 05 Mar. 2025.

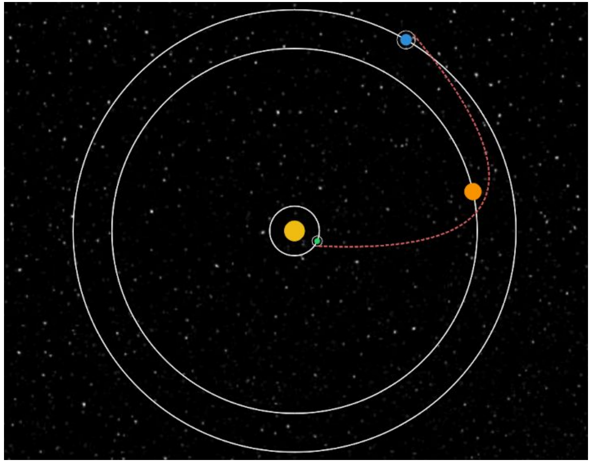
[24] “Uranus Orbiter and Probe.” Wikipedia, Wikimedia Foundation, 4 Feb. 2025, en.wikipedia.org/wiki/Uranus_Orbiter_and_Probe. Accessed 05 Mar. 2025.

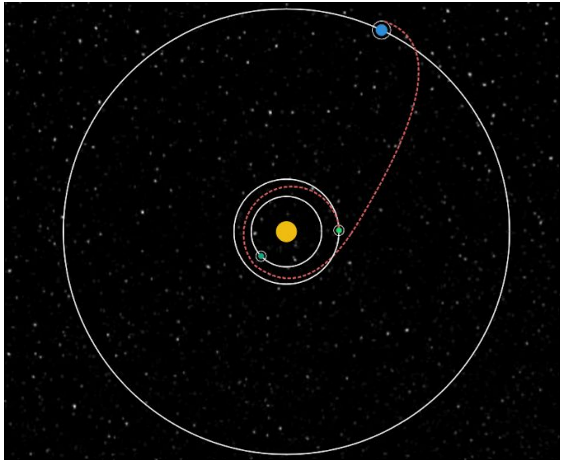
[25] “Why We Need to Return to Uranus and Neptune.” BBC Sky at Night Magazine, 8 Jan. 2024, www.skyatnightmagazine.com/space-science/spacecraft-mission-uranus-neptune. Accessed 05 Mar. 2025.

Backup Slides

Reaching Uranus

1. Launch Window: 2031 - 2032
   - Launch Vehicle: Falcon heavy rocket [13]
   - Use Jupiter as a flyby [7]
   - Use Aerocapture to transition from a hyperbolic trajectory to elliptical orbit [12]
   - Arrival: 2044
2. Launch Window: After 2032 [7]
   - Launch Vehicle: Starship [13]
   - Use Earth and/or Venus as flybys
   - Flight Time: 14+ years





Contributors: Jace, Julianne
Presenting: Jace

AURORA by the Numbers [7]

1. Mission Lifetime: 18.5 yrs
2. Total ΔV: 2708 m/s
   a. Aerocapture dissipates up to a ΔV equivalent of 4.2 km/s
3. Mass Budget: 6552 kg total
   a. Dry mass: 3429 kg
   b. Wet mass: 3123 kg
4. Design Life
   a. Orbiter: 18.5 yrs
   b. Probe: 13.7 yrs
5. Cost: $2.8B* (FY$25)

Extra Math stuffs

https://drive.google.com/drive/folders/1Qlun6EF0v472eOMXXokHxa6B2tBLNkdv (NASA Mission Study on Uranus Orbiter + Probe Requested by 2023-2032 Decadal Survey)

https://discovery.larc.nasa.gov/PDF_FILES/Aerocapture_std_briefing_June10_v2.pdf

https://www.hou.usra.edu/meetings/icegiants2014/presentations/Day_3/Agrawal_2008.pdf - 3000 km

https://arc.aiaa.org/doi/pdfplus/10.2514/6.2025-1510 - altitude 1000 km

MIT AEROASTRO

Launch Feasibility with Starship

Contributors: Tamara
Presenting: Tamara

- Starship capable of direct transfer to Uranus [13]
- Starship UOI would require a larger propellant mass, most likely located in the main tanks with a high boil-off risk.

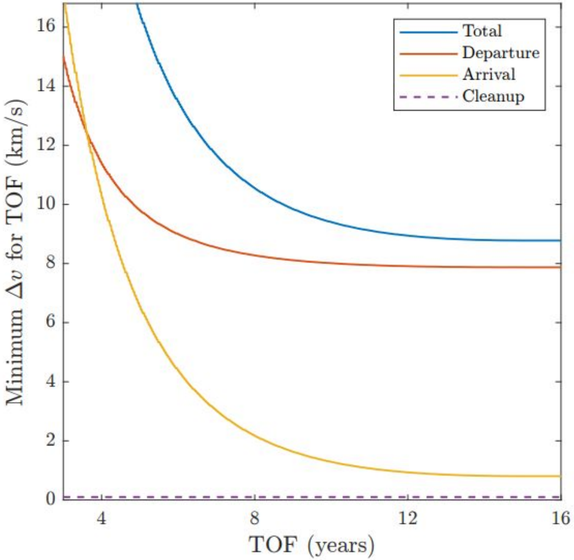


Figure 9: Plot of Δv and TOF tradeoff for Uranus direct transfer.

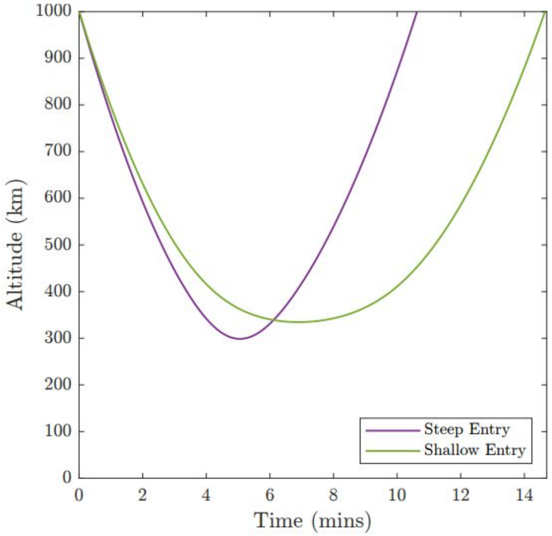


Figure 12: Example aerocapture bounding trajectories for Starship configuration with both fin sets deflected arriving with v_∞ of 8 km/s.

Table 7: Baseline UOP mass and propulsive properties, from [2].

Parameter	Value
Flight system launch mass	7235 kg
Inserted mission mass at Uranus	4919 kg
Total notional mission Δv	2708 m/s
Δv for cruise and UOI	1887 m/s
Δv available after UOI	821 m/s

Entering Uranus Orbit

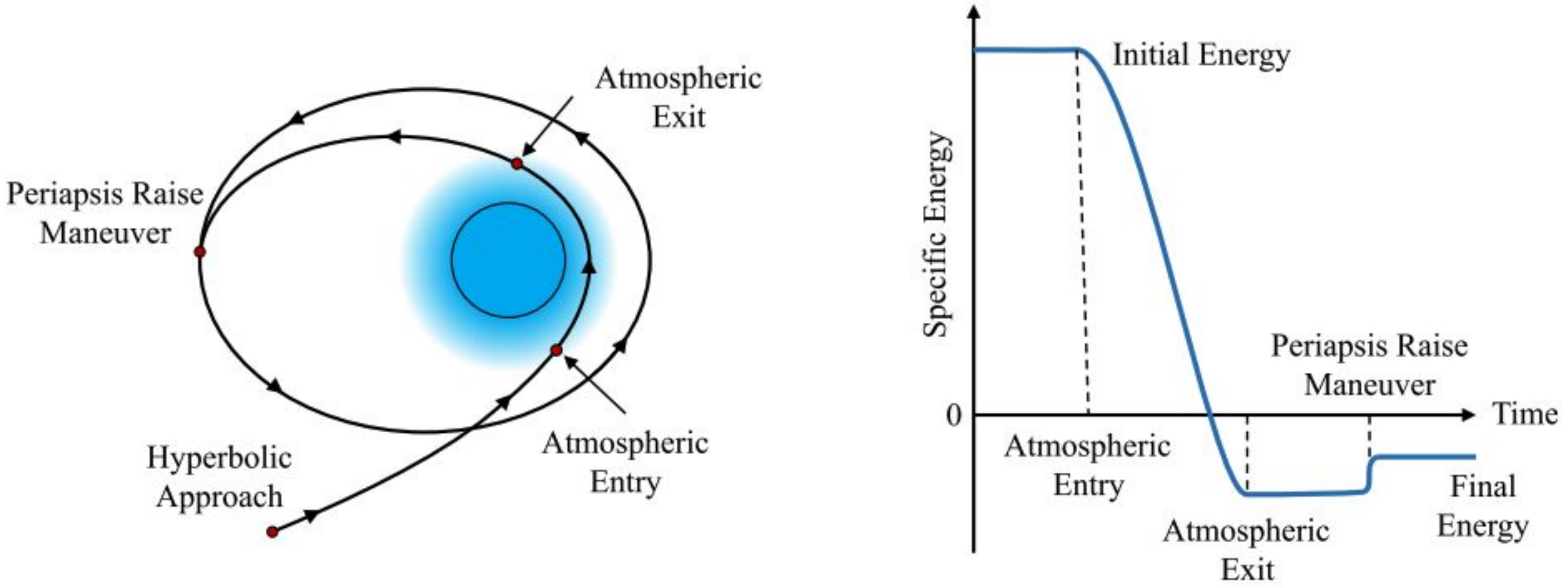
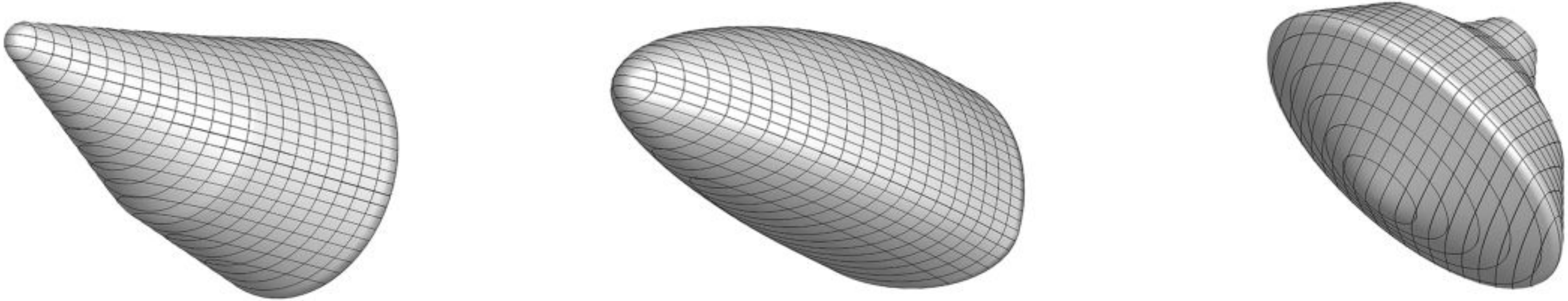


Fig. 1 Diagrams showing example aerocapture trajectory and spacecraft specific energy over time. [12]

MIT AEROASTRO Contributors: Jace, Julienne
Presenting: Jace

Heat Shield Shapes



a) Florence (1981), $L/D = 2.0$ [8] b) Ellipsled (2004), $L/D = 0.6$ [10] c) Blunt-Body (2023), $L/D = 0.25$ [7]

[12]

Mission Δv

Phase	Maneuver Name	Δv (m/s) Deterministic	Δv (m/s) Statistical
Cruise	Launch Cleanup		20
	DSM	660	
	DSM Cleanup		30
	Earth Flyby Targeting/Bias		50
	Jupiter Flyby Targeting		30
	Phase Subtotal	**660**	**130**
Capture & Probe Release	UOI targeting		10
	UOI	1,087	
	UOI Cleanup		45
	Probe Targeting	15	
	Probe Separation		
	Orbiter Divert	29	
	Orbiter/Probe Statistical		5
	PRM	171	
	PRM Cleanup		20
	Phase Subtotal	**1,302**	**80**

Tour	Miranda Targeting	0	
	Miranda Statistical		6
	Ariel Targeting	17	
	Ariel Statistical		6
	Umbriel Targeting	0	
	Umbriel Statistical		6
	Titania Targeting	0	
	Titania Statistical		6
	Oberon Targeting	0	
	Oberon Statistical		6
	Phase Subtotal	**17**	**30**
Other	Disposal	216	
	Unallocated Margin	148	
	ACS		125
	Subtotal	**364**	**125**
Mission Total		**2343**	**365**
		2708	

[7]

Contributors: Jace, Julienne
Presenting: Jace

Scientific Probe Technology

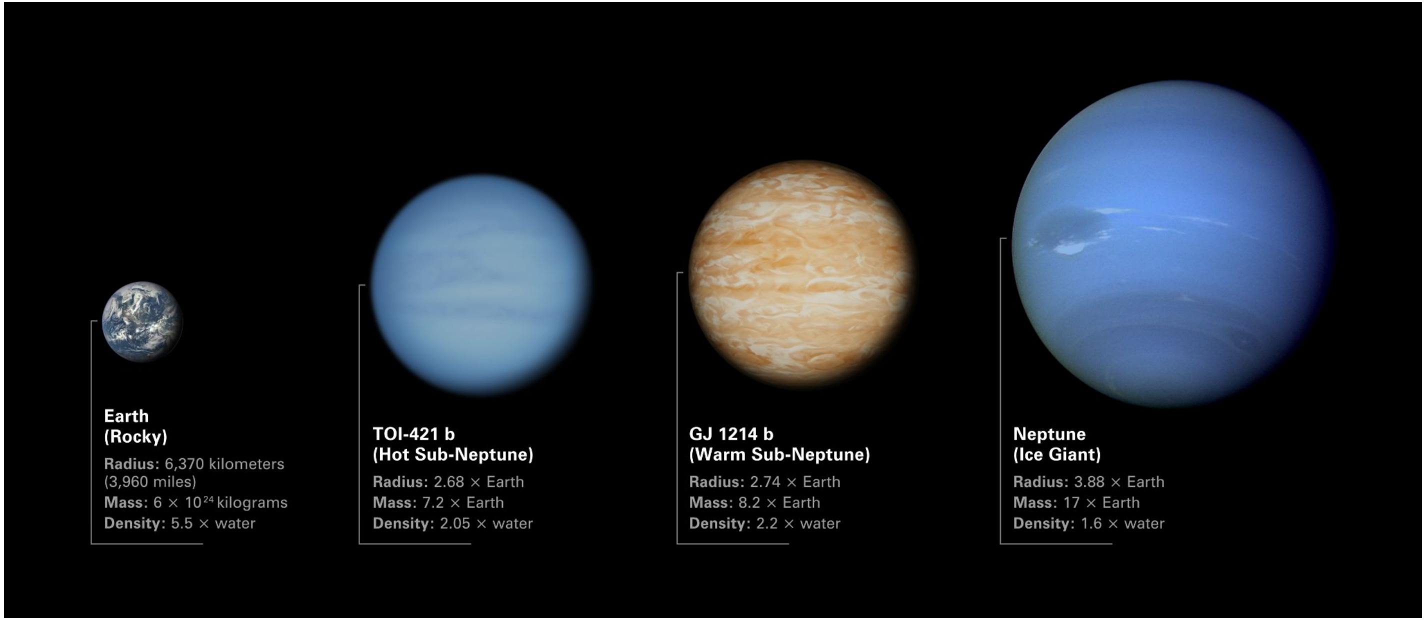
Contributors: Tamara, Julienne
Presenting: Julienne

Scientific payload / in-situ probe:

- https://pmc.ncbi.nlm.nih.gov/articles/PMC7099645/#S5 (reviewing previous design concepts for an Ice Giant probe)
  - Note technical challenges mentioned in the article for next slide
- Article on in situ probes (link)
- Atmosphere (chemical composition)
- Temperature
- Radar / comms

Exoplanet Research

Contributors: Cynthia
Presenting: Cynthia



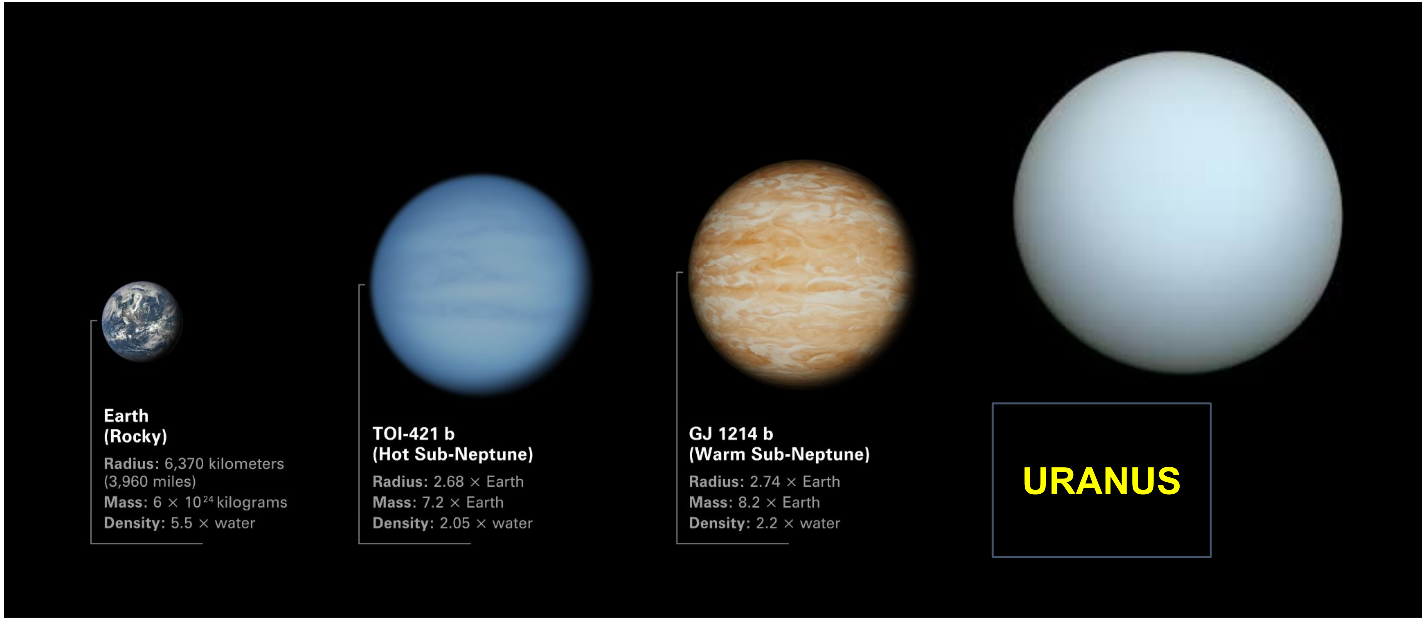
Over half of currently discovered exoplanets are categorized as sub-neptunes [2]

MIT AEROASTRO

Exoplanet Research

Contributors: Cynthia
Presenting: Cynthia

Mini-Neptunes
Sub-Neptunes

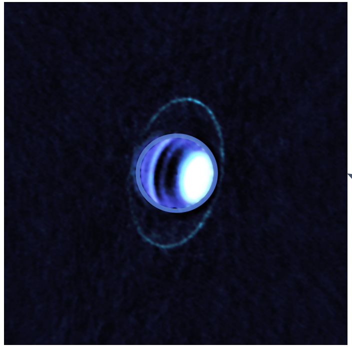


Uranus' Atmosphere

Contributors: Cynthia
Presenting: Cynthia

Coldest atmosphere in the solar system, most transparent

- Atmosphere is particularly hard to detect! Could give info on light curves of exosolar systems w/ sub-Neptunes [14]
- Avg temp: -320deg F (link) [14]



Composite image of Uranus's atmosphere and rings at radio wavelengths, taken with the Atacama Large Millimeter/submillimeter Array (ALMA) in December 2017. The image shows thermal emission, or heat, from the rings of Uranus for the first time, enabling scientists to determine their temperature is a frigid 77 K (-320 F). Dark bands in Uranus's atmosphere at these wavelengths show the presence of radiolight-absorbing molecules, in particular hydrogen sulfide (H2S) gas, whereas bright regions like the north polar spot contain very few of these molecules [5]

MIT AEROASTRO

Uranus' Moons

Contributors: Cynthia
Presenting: Cynthia

- Little info about moons
- Really chemically interesting (on same axis)
  - Info about planet formation
  - Might have oceans (we don't know)
- Could inform us about the makeup of exomoons and the chemical signatures to look for
- https://www.space.com/22201-uranus-moons.html

Why probe and not just JWST

Contributors: Tamara, Cynthia
Presenting: Tamara

- JWST cannot ….
- Atmospheric composition (cannot gain all necessary information from external measurements)
  - How does atmospheric circulation function, from interior to thermosphere, in an ice giant? (https://en.wikipedia.org/wiki/Uranus_Orbiter_and_Probe)

Why Uranus and not Neptune

Contributors: Cynthia
Presenting: Cynthia

- Axial tilt is really interesting
  - Magnetic field
- Atmospheric condition
- Flexible launch dates
- Voyager 2 – solar storm

[19]

Uranus Orbiter and Probe	Neptune Odyssey
• End-to-end viable mission concept on currently available launch vehicle • Flexible launch dates starting in 2031 through 2038+ • No new technologies required • Low-Medium risk (only large mission TRACEd to receive this)	• Lacks demonstrated trajectory and launch date within the decade on currently available launch vehicle • Uncertainties in power requirements and possible need for solar electric propulsion if neither SLS nor Jupiter gravity assist are available • Accommodation on current launch vehicles unclear (faring size)

MIT AEROASTRO