Design of Interplanetary Trajectories for Uranus Probe and Orbiter Mission Including Two-Planet Saturn-Uranus Opportunity

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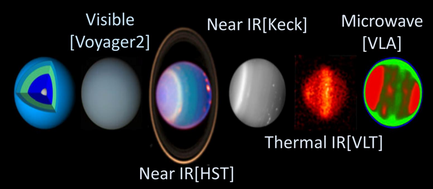
URANUS—AN ICE-GIANT PLANET

- Ice Giants have less H and He, and more "ices" (H_2O, NH_3, CH_4, etc.)
- Majority of observed exoplanets are ice-giants[1]
- Humankind's last encounter with Uranus was Voyager 2 in 1986[2]
- One of the great remaining unknowns of the Solar System[3]

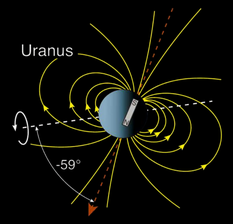


Images of Uranus from Arridge et al.[4]

WHY A MISSION TO URANUS?

Uranus has unique features:[3]

1. Atmospheric dynamics due to extreme axial tilt
2. Unusual magnetosphere geometry
3. Unexplained energy balance
4. Dynamically evolving rings and moons



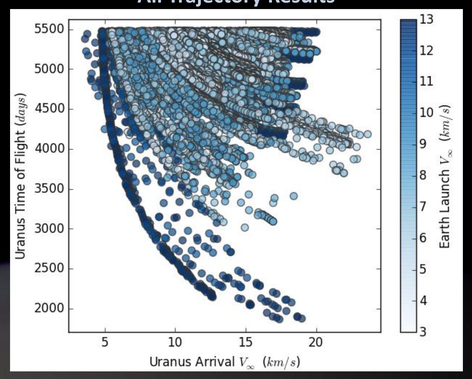
OBJECTIVE OF STUDY

Identify trajectories to Uranus with launch dates from 2023 to 2028, and potentially aid mission concept studies for the next Decadal Survey.

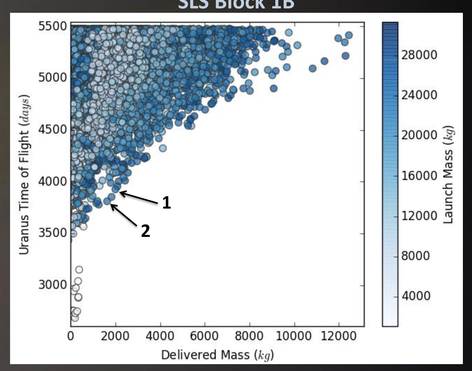
TRAJECTORIES TO URANUS

- 17 gravity-assist combinations considered
- Trajectories searched in 5-day increments
- Patched-conic model employed
- Delivered-mass estimated using SLS and Atlas V
- Jupiter in poor alignment for gravity assist

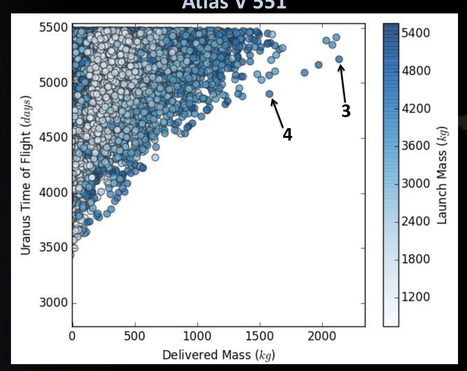
All Trajectory Results



SLS Block 1B



Atlas V 551

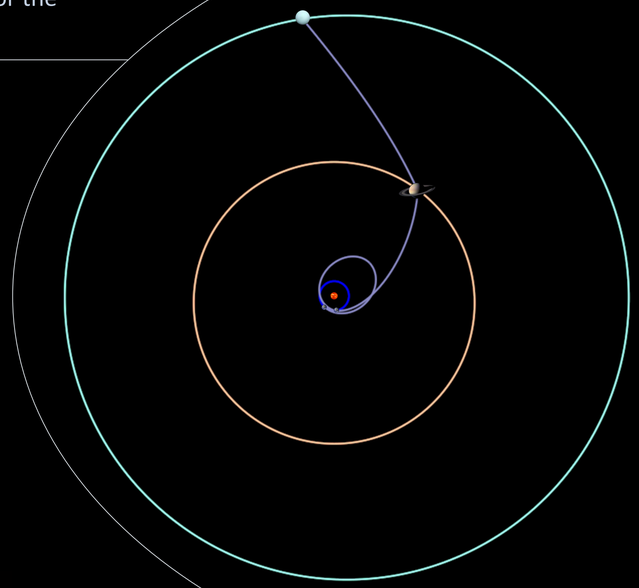


No.	Case	Launch Date	TOF, yr	Arrival Date	Delivered Mass, mt
1	VEE0U (SLS)	6/10/2023	10.7	3/10/2034	2.0
2	VEE0U (SLS)	5/31/2023	10.4	11/5/2033	1.6
3	VEE0U (Atlas V 551)	10/7/2026	14.3	1/16/2041	2.1
4	VEE0U (Atlas V 551)	10/2/2026	13.4	3/3/2040	1.6

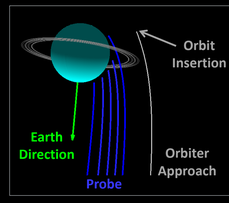
0 = Maneuver, E = Earth, V = Venus, U = Uranus

Saturn-Uranus Trajectory

Launch May 6, 2023

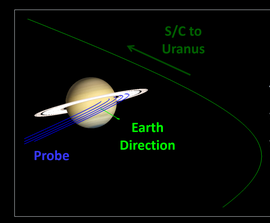


Uranus Arrival



September 12, 2034
$TOF_{E\text{-}U}$ = 11.4 years
$TOF_{S\text{-}U}$ = 4.8 years
V_∞ = 10.7 km/s
V_{entry} = 23.0 km/s

Saturn Flyby



November 28, 2029
$TOF_{E\text{-}S}$ = 6.6 years
V_∞ = 8.7 km/s
V_{entry} = 36.2 km/s

A rare opportunity—Saturn-Uranus alignment only repeats every 45 years

TWO-PLANET SATURN-URANUS OPPORTUNITIES

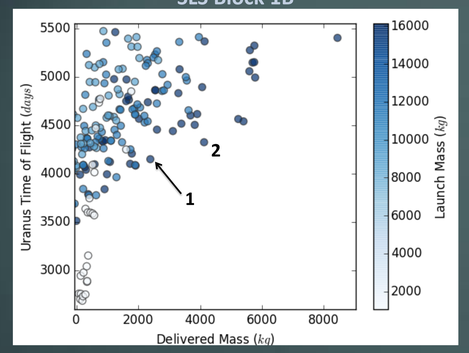
A Saturn-Uranus mission permits:

- Sending *first probe to Saturn*, and *first probe-orbiter to Uranus*
- An opportune arrival time for Uranus atmospheric science
- Identical probe design for both planets

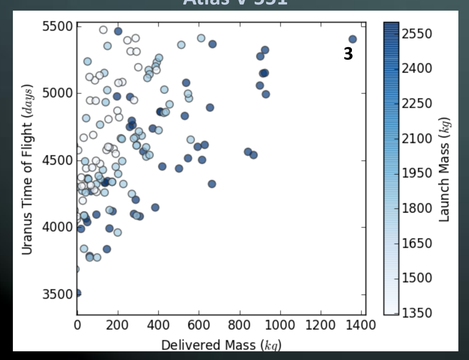
Why probe Saturn?
To determine:[3]

- Noble gas abundances
- Isotopic ratios of H, C, N, and O
- Atmospheric structure (pres., temp., and density)

SLS Block 1B



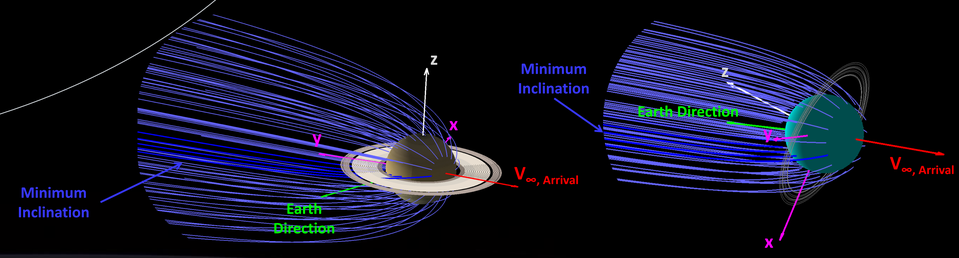
Atlas V 551



No.	Case	Launch Date	TOF, yr	Arrival Date	Delivered Mass, mt
1	0E0SU (SLS)	5/6/2023	11.4	9/12/2034	2.4
2	0E0SU (SLS)	6/19/2026	11.8	4/20/2038	4.1
3	0E0SU (Atlas V 551)	6/4/2025	14.8	3/19/2040	1.4

0 = Maneuver, E = Earth, S = Saturn, U = Uranus

LOCUS OF APPROACH TRAJECTORIES



Family of approach trajectories for various entry flight path angles, latitudes, azimuths, etc.

FUTURE OUTLOOK

A significant amount of follow-on work will explore details resulting from this preliminary trajectory design study. Some of these tasks have already been identified, namely:

- Investigate uniqueness of Saturn-Uranus, two-planet mission opportunity
- Compute optimal trajectories (including maneuver locations) for maximum delivered mass
- Investigate several key trajectories in higher fidelity (including Saturn-Uranus opportunity)
- Develop high-fidelity entry analysis for probes at Saturn and Uranus
- Investigate optimal, gravity-assist, low-thrust trajectories to Uranus
- Compare Atlas V vs SLS opportunities including assessment of cost and science return

ACKNOWLEDGMENT The authors would like to thank Mr. Alec Mudek for his support in this work.

REFERENCES [1]Batalha, N. M., et al. (2013) The Astrophysical Journal Supplement Series, 204(2), 24. [2]Bergstralh, J. T., et al., (ed.) (1991) Uranus. University of Arizona Press, Tucson, AZ. [3]Squyres, S. et al. (2011), Vision and Voyages for Planetary Science in the Decade 2013–2022, National Academies Press. [4]Arridge, C. S., et al. (2012) Experimental Astronomy, 33(2-3), 753-791.