Study of Direct, Planetary Insertion Orbits from Space Elevators

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Presentation Agenda

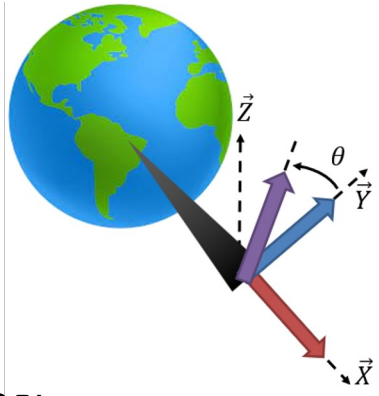
- Purpose of the Study
- Space Elevator Parameters
- Space Elevator Release Concepts
- Study Parameters
- Results of the Simulations
- Conclusions
- Future Work

Purpose of the Study

- Space elevators are described as “the green road to space”
  - No rocket fuel is required to get mass to the apex anchor
- Wanted to know if space elevators could be “the green road to **interplanetary** space”
  - No midcourse corrections, phasing burns, or plane changes to achieve a fly-by
  - Creating direct, planetary insertion orbits
- The availability of interplanetary transfers create:
  - Extensive amounts of opportunities to colonize and explore the solar system
  - An ease of access for scientists to perform new scientific experiments across the solar system

Space Elevator Parameters

- Types of space elevators
  - Apex Release (Tier 0)
  - Centripetal Accelerators
    - **Free Release (Tier 1)**
    - **Ramped Release (Tier 2)**
    - **Rotated, Ramped Release (Tier 3)**
- Each space elevator has a length of 100,000km
  - The ramps have a 1,000 km radius



Departure Direction

Tier 1	$\vec{X}$
Tier 2	$\vec{Y}$
Tier 3	Within YZ plane, rotated about $\vec{X}$ by θ

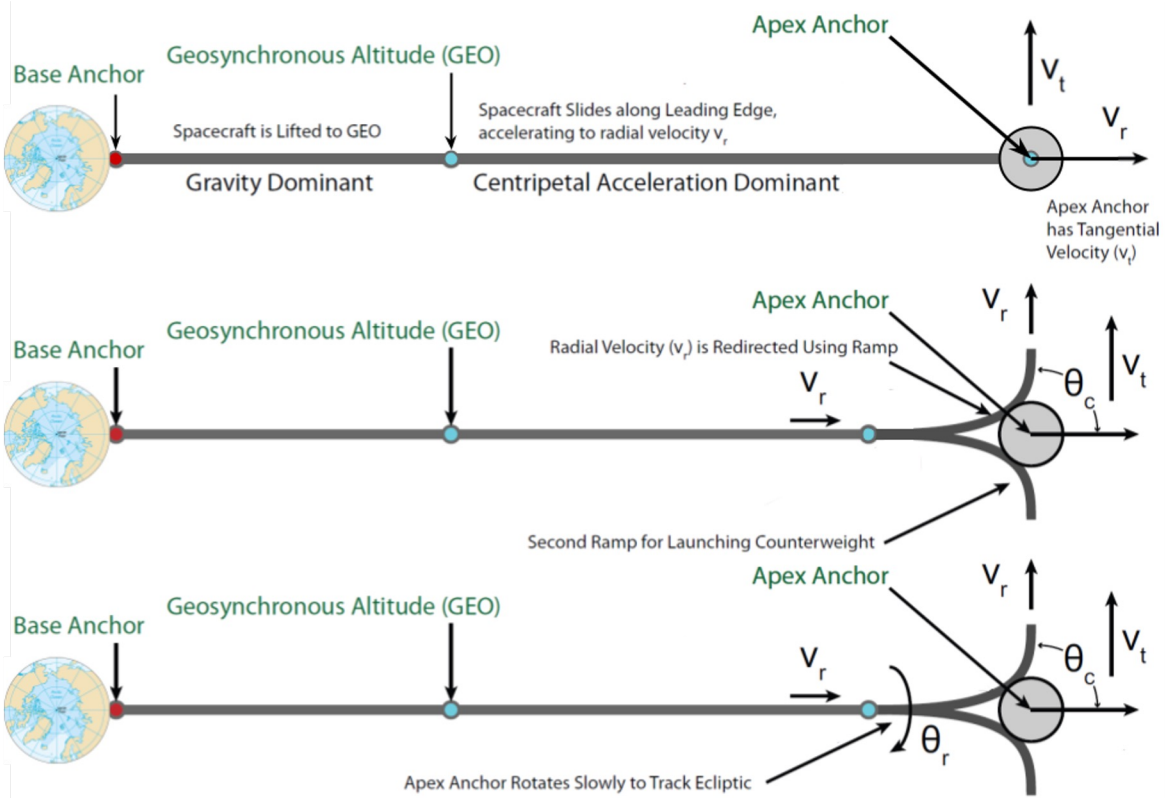
	Apex Release	Free Release	Ramped Releases
Furthest planet that can be flown-by	Mars	Jupiter	Can leave the solar system

Space Elevator Release Concepts

Tier 1: Original concept now with sliding

Tier 2: An apex ramp or skyhook, located at the apex anchor for redirection of radial velocity in tangential direction

Tier 3: A pivot point for slow rotation of the apex anchor used to track the ecliptic plane



Ideas and images from: Peet, Matthew M., "The Orbital Mechanics of Space Elevator Launch Systems," February 2021 Acta Astronautica 179(3711):153-171

Study Parameters

- Search window of 50 years
  - January 1st, 2022 to January 1st, 2072
- Used ephemerides from NASA JPL, DE405
  - Provided data for planetary positions and velocities so accurate and real time solutions can be simulated
- Transfer orbits are modeled on a day-by-day basis
- Max TOF equal to the respective Hohmann Transfer to target planet

Results of the Simulations (Jupiter)

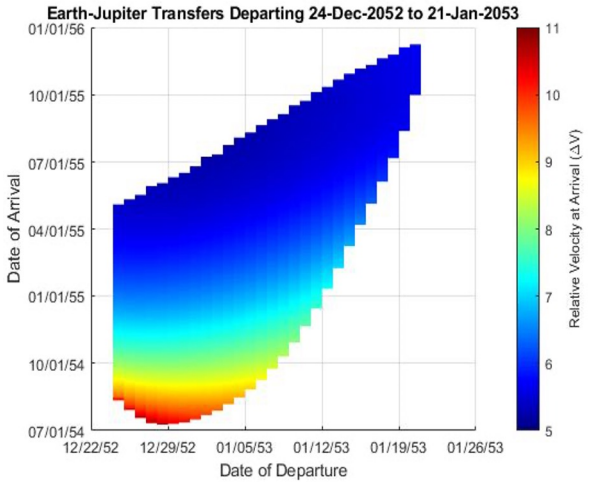
Interplanetary Transfer Statistics

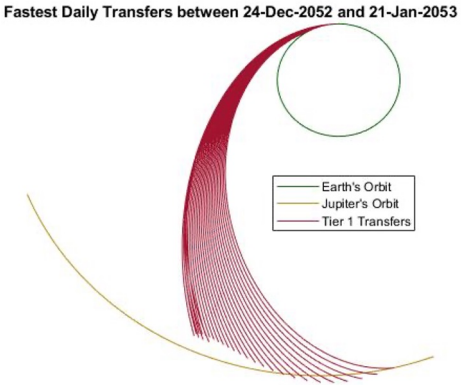
	Tier 1 (Free Release)	Tier 2 (Ramped Release)	Tier 3 (Rotated, Ramped Release)
# of Launch Windows over 50 years	7	12	43
Average Length of a Launch Window (days)	23	39	49
Minimum TOF (days)	526	230	230
Maximum TOF (days)	1095	1095	1095
Average TOF (days)	748	356	545

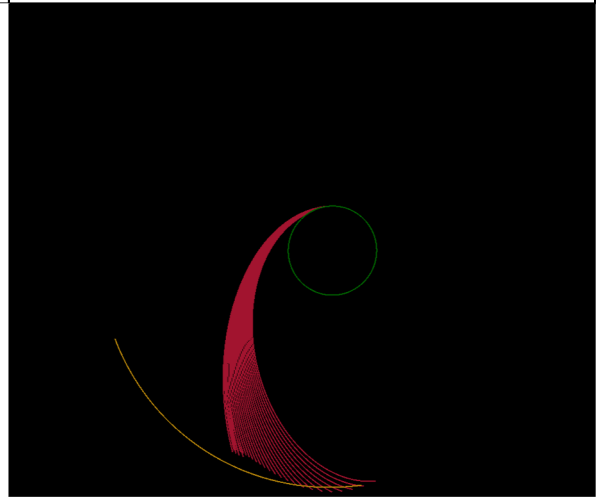
Results of the Simulations (Jupiter)

Tier 1 Transfer Window Analysis (Dec. 23rd, 2052 - Feb. 22nd, 2053)

Porkchop Plot	MATLAB Simulation	GMAT Simulation



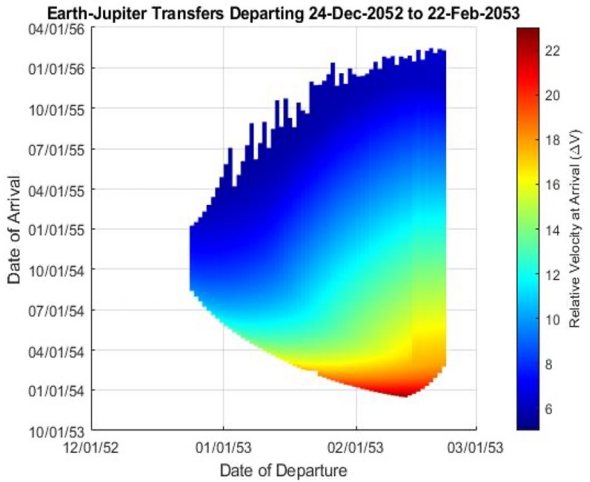


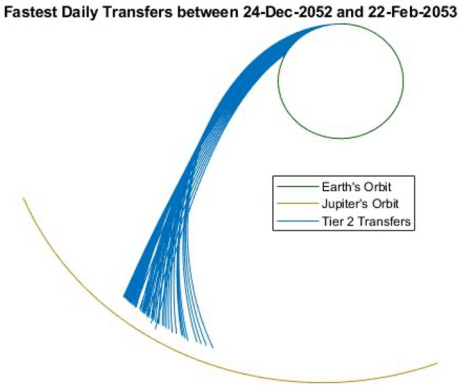


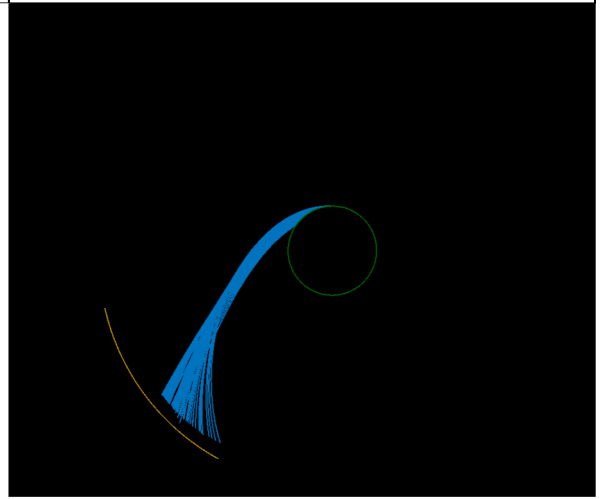
Results of the Simulations (Jupiter)

Tier 2 Transfer Window Analysis (Dec. 23rd, 2052 - Feb. 22nd, 2053)

Porkchop Plot	MATLAB Simulation	GMAT Simulation



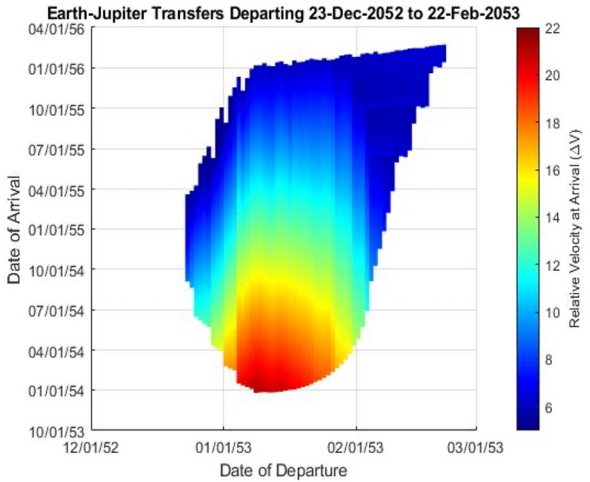


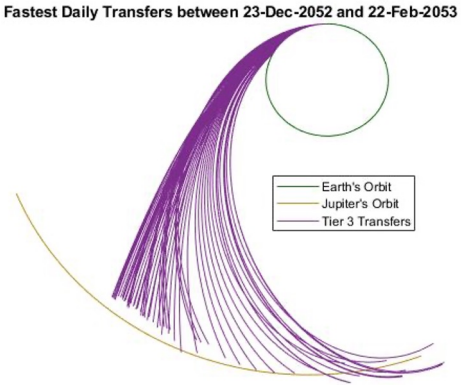


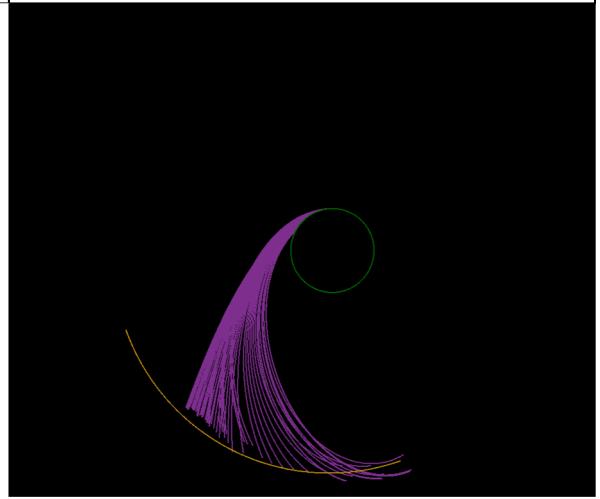
Results of the Simulations (Jupiter)

Tier 3 Transfer Window Analysis (Dec. 23rd, 2052 - Feb. 22nd, 2053)

Porkchop Plot	MATLAB Simulation	GMAT Simulation







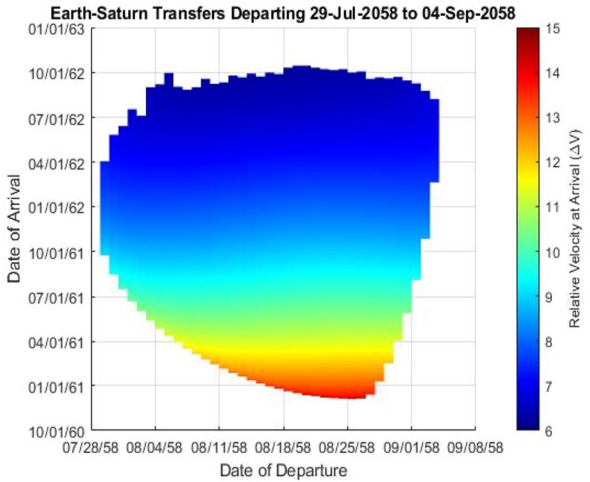
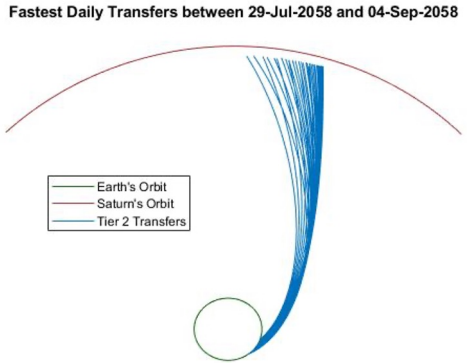
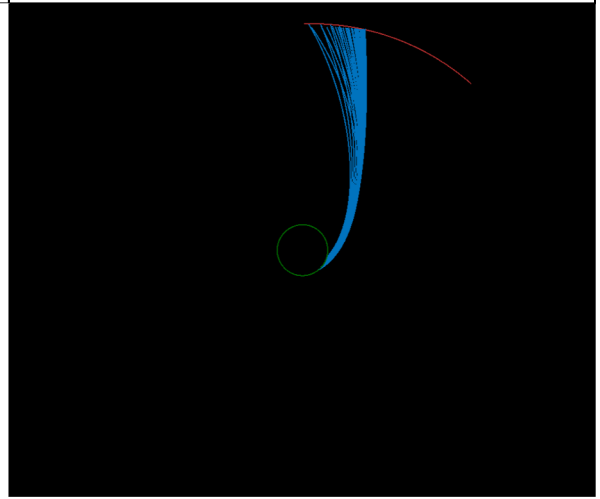
Results of the Simulations (Saturn)

Interplanetary Transfer Statistics

	Tier 1 (Free Release)	Tier 2 (Ramped Release)	Tier 3 (Rotated, Ramped Release)
# of Launch Windows over 50 years	N/A	10	40
Average Length of a Launch Window (days)	N/A	36	27
Minimum TOF (days)	N/A	593	593
Maximum TOF (days)	N/A	2546	2555
Average TOF (days)	N/A	1055	1168

Results of the Simulations (Saturn)

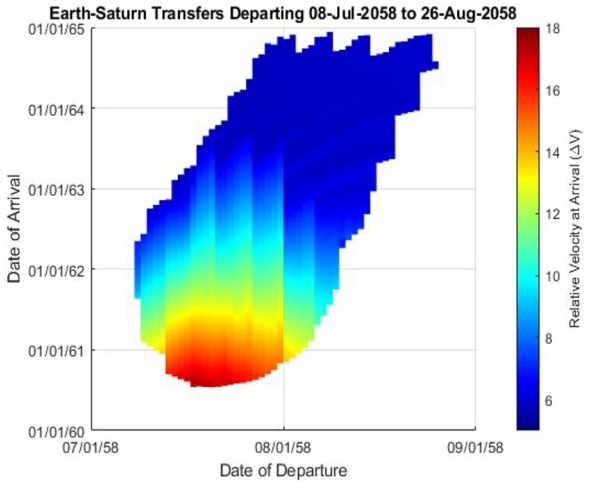
Tier 2 Transfer Window Analysis (Jul. 8th, 2058 - Sep 4th, 2058)

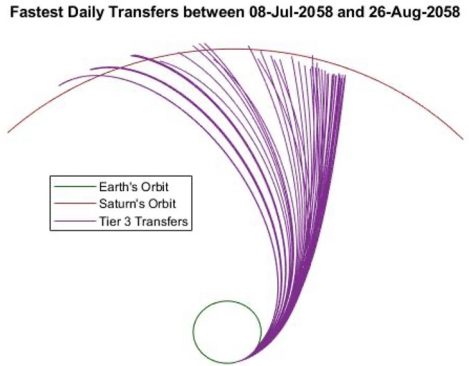
Porkchop Plot	MATLAB Simulation	GMAT Simulation
		

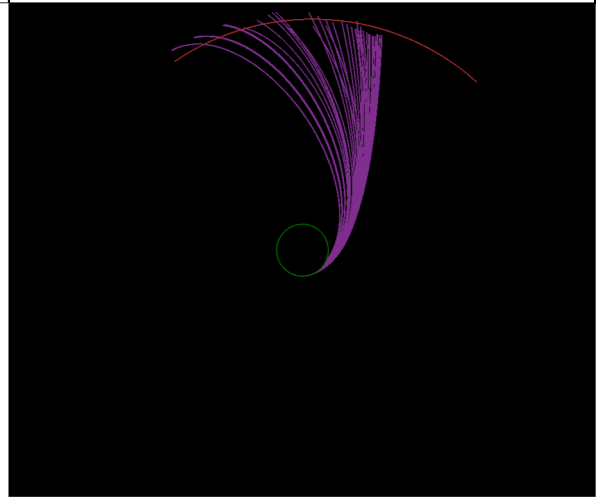
Results of the Simulations (Saturn)

Tier 3 Transfer Window Analysis (Jul. 8th, 2058 - Sep 4th, 2058)

Porkchop Plot	MATLAB Simulation	GMAT Simulation







Results of the Simulations (Uranus)

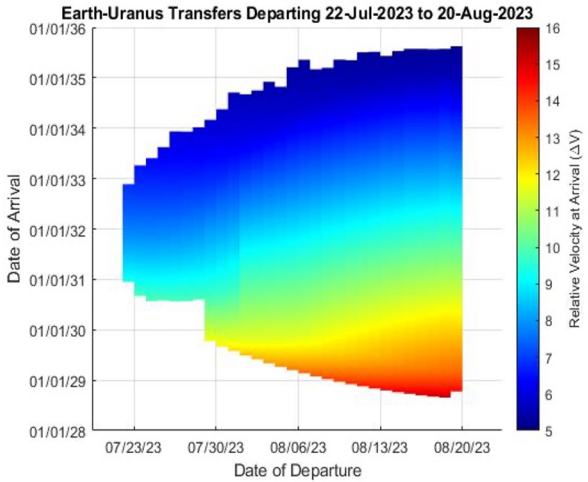
Interplanetary Transfer Statistics

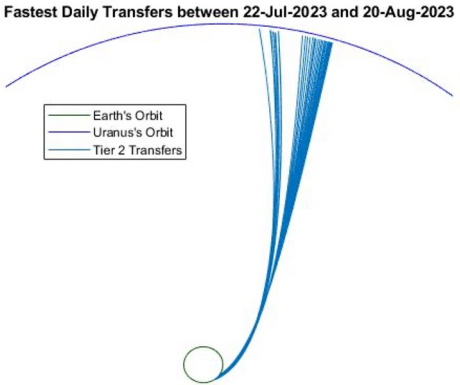
	Tier 1 (Free Release)	Tier 2 (Ramped Release)	Tier 3 (Rotated, Ramped Release)
# of Launch Windows over 50 years	N/A	3	33
Average Length of a Launch Window (days)	N/A	39	21
Minimum TOF (days)	N/A	1624	1624
Maximum TOF (days)	N/A	4999	6204
Average TOF (days)	N/A	2531	3551

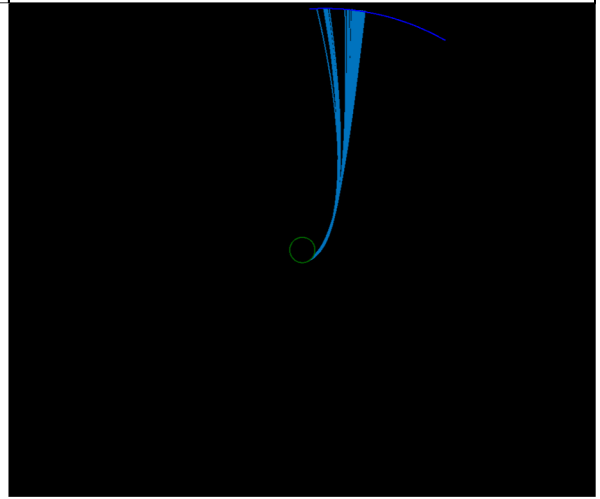
Results of the Simulations (Uranus)

Tier 2 Transfer Window Analysis (Jul. 6th, 2023 - Aug 30th, 2023)

Porkchop Plot	MATLAB Simulation	GMAT Simulation



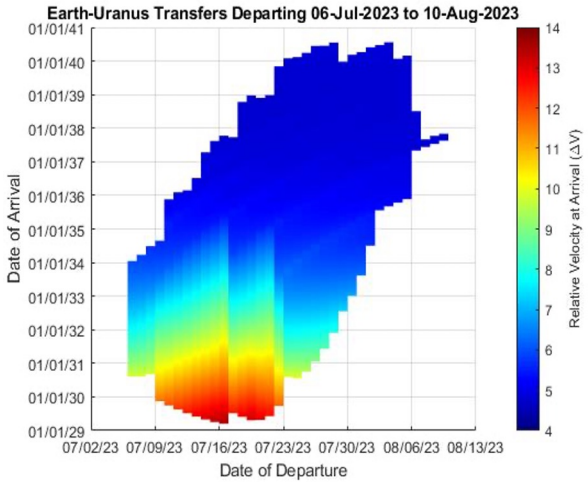


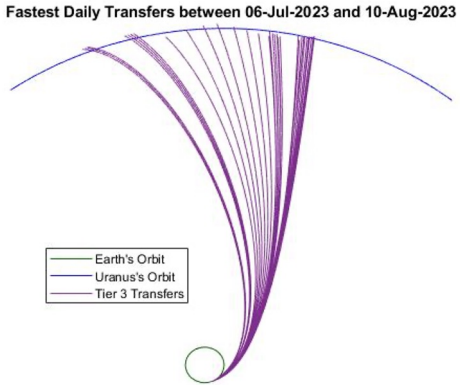


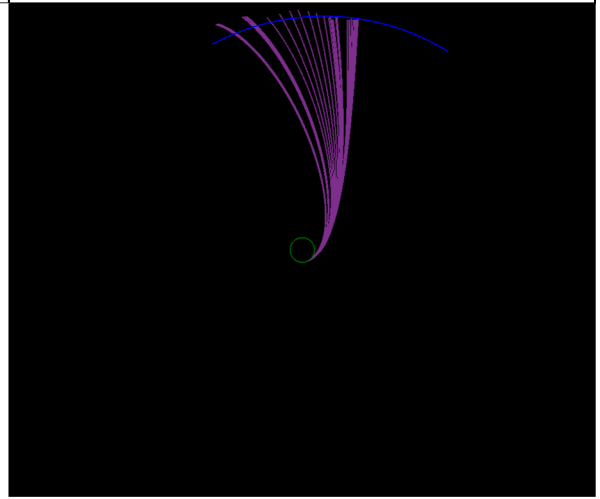
Results of the Simulations (Uranus)

Tier 3 Transfer Window Analysis (Jul. 6th, 2023 - Aug 30th, 2023)

Porkchop Plot	MATLAB Simulation	GMAT Simulation







Results of the Simulations (Neptune)

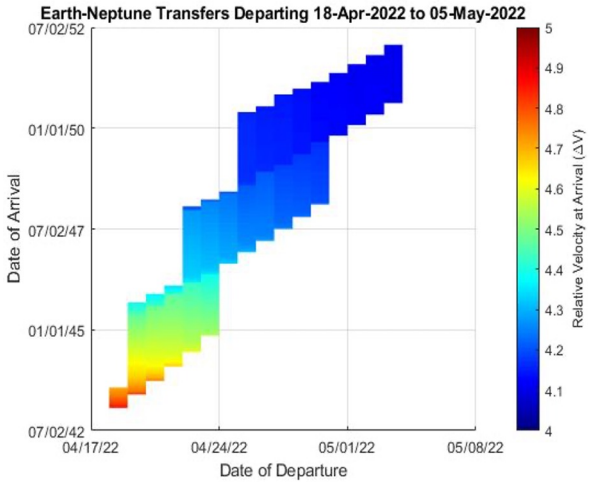
Interplanetary Transfer Statistics

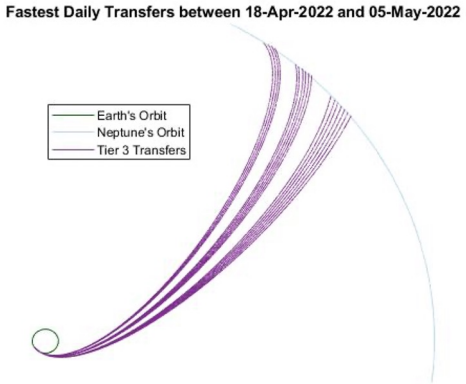
	Tier 1 (Free Release)	Tier 2 (Ramped Release)	Tier 3 (Rotated, Ramped Release)
# of Launch Windows over 50 years	N/A	N/A	6
Average Length of a Launch Window (days)	N/A	N/A	13
Minimum TOF (days)	N/A	N/A	7129
Maximum TOF (days)	N/A	N/A	10944
Average TOF (days)	N/A	N/A	8700

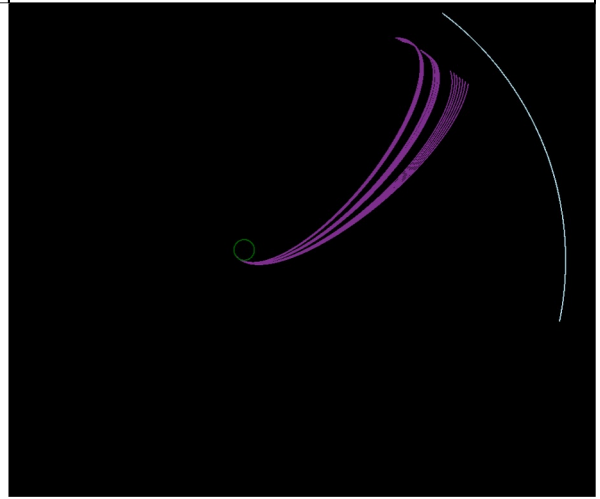
Results of the Simulations (Neptune)

Tier 3 Transfer Window Analysis (Apr. 18th, 2022 - May 5th, 2022)

Porkchop Plot	MATLAB Simulation	GMAT Simulation







Conclusions

- Space elevators can also be referred to as “the green road to **interplanetary** space”
  - For free release or ramped release elevators, extensive launch opportunities exist over the next 50 years
- Space elevators using centripetal acceleration outperform apex releases
  - For a fixed apex, ramped releases will have the greatest orbital energy
    - Providing the potential to leave the solar system
  - An apex release needs roughly twice the length of elevator compared to a ramped release
- Each space elevator simulated has different orbital trends
  - Free release (Tier 1): lower energy and averaged longer TOFs
  - Ramped release (Tier 2): higher energy and averaged shorter TOFs
  - Rotated, ramped release (Tier 3): Average of Tier 1 and 2

Future Work

- Optimize code to intercept Mars and Venus
  - Opening the door to out-of-plane targeting
- Perform simulations with longer space elevators
  - Up to 175,000 km in length
- Simulate space elevators in different windows in time
  - Perhaps looking at the interplanetary opportunities over the next 100 years

Thanks for listening.

Questions? Email me at geneluevano@asu.edu