AUTOMATED SENSITIVITY ANALYSIS OF INTERPLANETARY TRAJECTORIES

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AGENDA

- **Motivation**
- Methodology
- Global Optimization
- Case Study 1
- Case Study 2
- Summary

MOTIVATION

- First task for mission designer is typically to create a nominal/baseline trajectory
- Second task is often to perform sensitivity analysis. The objective is to quantify the effects of changes to:
  - Operational constraints
  - Sub-system requirements
  - Off-nominal spacecraft performance
- Mission design is human-labor intensive and therefore expensive
- Computation time is not and is therefore cheap
- **Goals:**
  - **Transfer as much work-load as possible to computers (automation!)**
  - **Quantify entire design space**
  - **Find better mission design solutions than possible otherwise**

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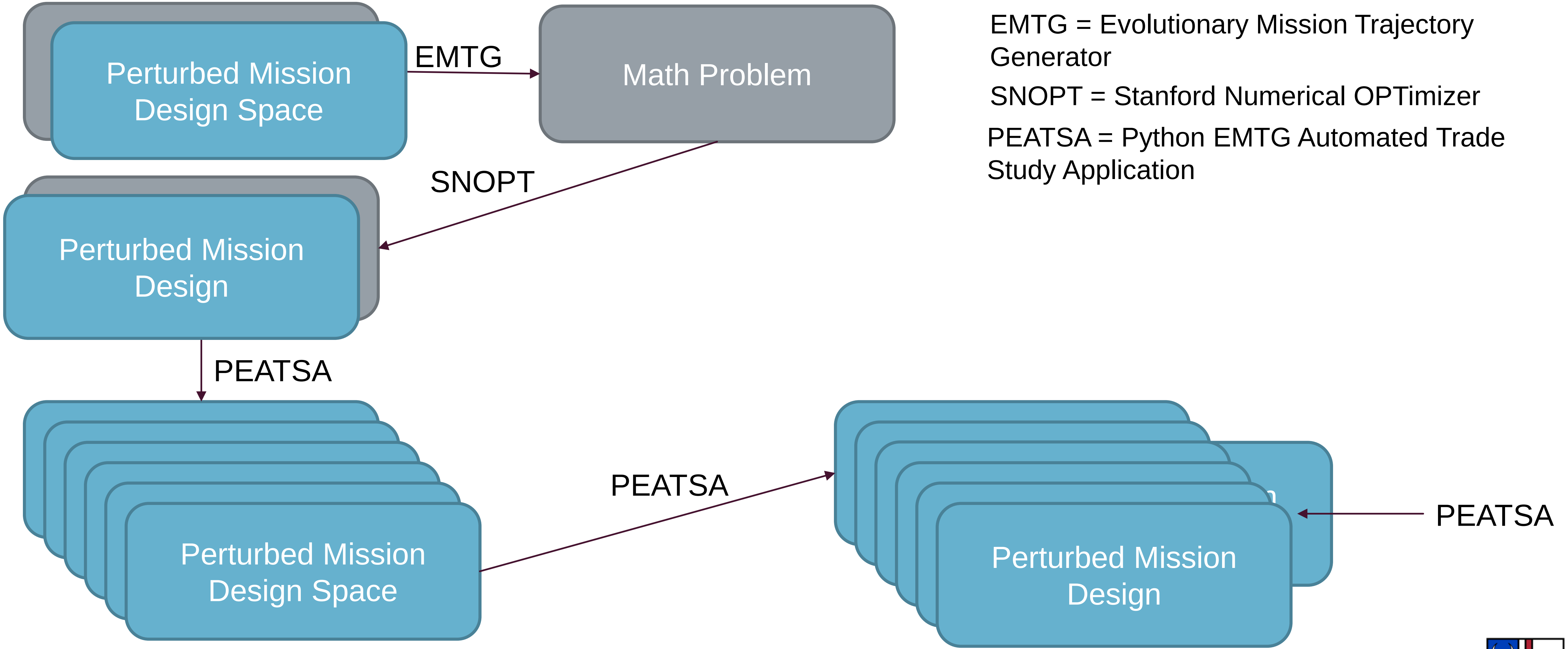
METHODOLOGY

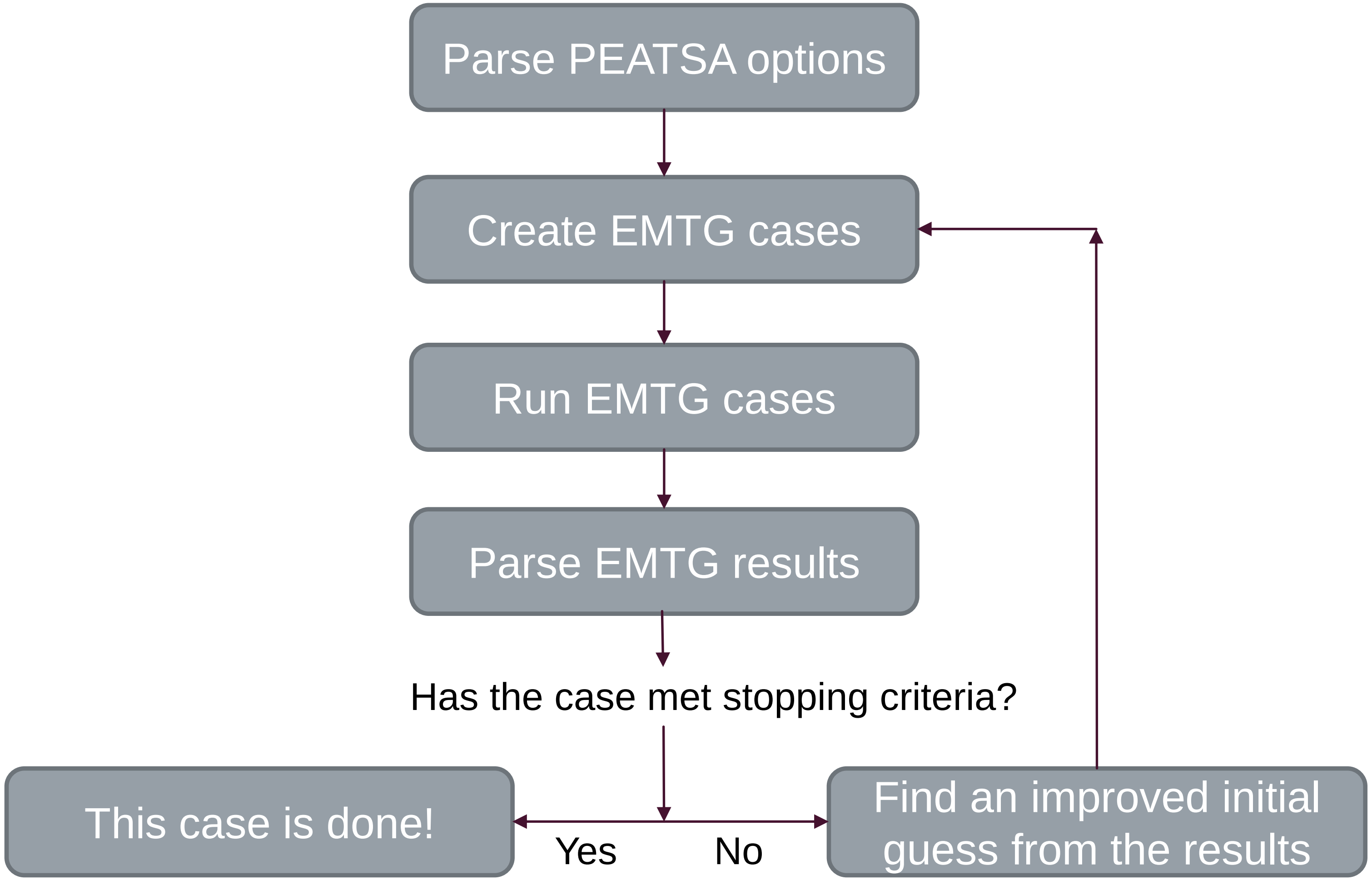


EMTG = Evolutionary Mission Trajectory Generator

SNOPT = Stanford Numerical OPTimizer

PEATSA = Python EMTG Automated Trade Study Application

METHODOLOGY



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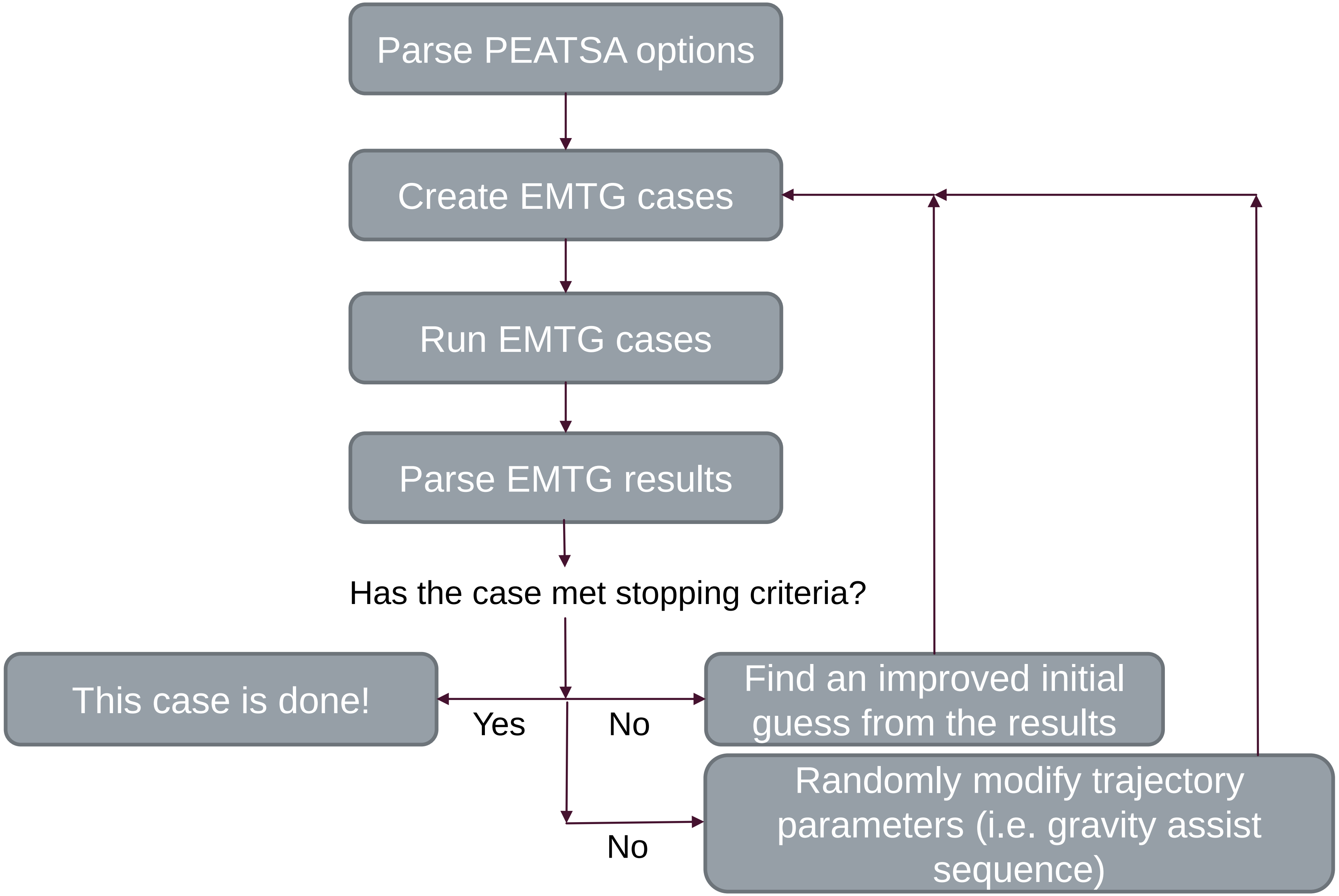
GLOBAL OPTIMIZATION

- If trajectory solver has no global optimization capability (local only), then re-seeding with improved initial guesses is crucial
- If trajectory solver DOES have global optimization capability, improved re-seeding is still helpful
- EMTG uses monotonic basin-hopping for global optimization
  - This process is stochastic.
  - No deterministic way to know if a global optimum has been reached ------> **trendlines can help**
  - No deterministic way to determine necessary run-time -------> **frequent iterations can eliminated wasted run-time after optimal solution has been found**
  - Currently, EMTG hoppers are serial only ------> **re-seeding effectively creates parallel hoppers**
- Global optimality also includes modify options that cant be modified in a fixed local optimization
  - **Between iterations, PEATSA can modify these fixed parameters**
    - **Flyby sequence**
    - **Target small-body**

GLOBAL OPTIMIZATION



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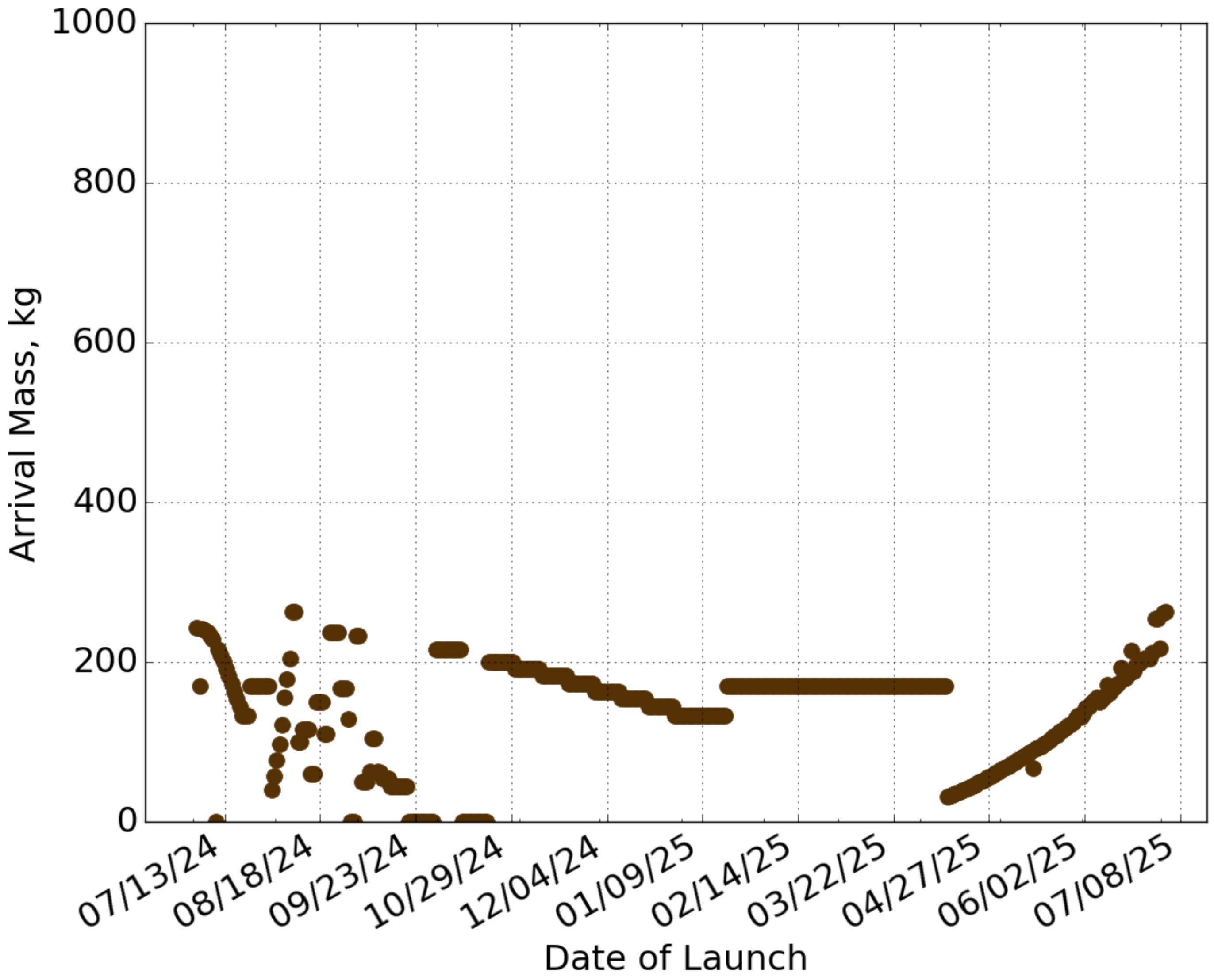
CASE STUDY 1 – URANUS MISSION LAUNCH WINDOW

- Goal: Uranus moon tour
- Assume that designer has zero knowledge of useful flyby sequence
- Launch sometime in late 2024 or early 2025
- Required 8 minutes of human labor for setup, and 12 wall clock-hours of computation time on a 64 core server

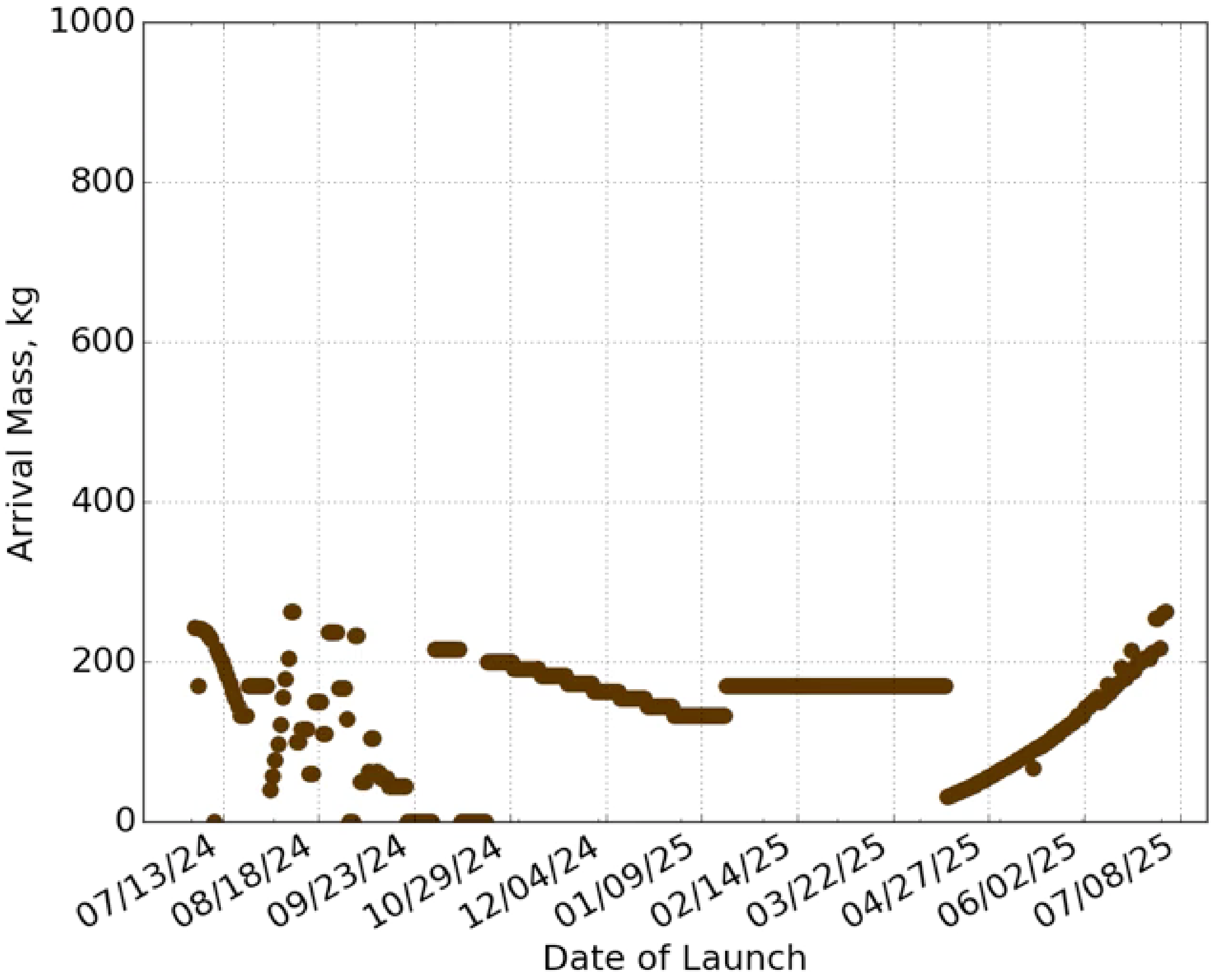
Mission Parameters	
Propulsion model	impulsive
Maximum flight time	12 years
Maximum numbers of DSMs	1 per flyby
Launch Vehicle	Atlas V 551
Spacecraft Isp	220 seconds
Intercept velocity	< 7 km/s
EMTG objective	maximum mass
EMTG run-time per iteration	60 seconds
PEATSA Options	
run_type	launch window
sorting_criteria	launch date
comparison_criteria	maximum final mass
wait_for_guess	yes
modify_flybys	yes
maximum_flybys	5
flyby_bodies	Venus, Earth, Mars, Jupiter, Saturn
options_to_vary	launch date
option_ranges	July 2024 through June 2025

CASE STUDY 1 – URANUS MISSION

- Iteration 0

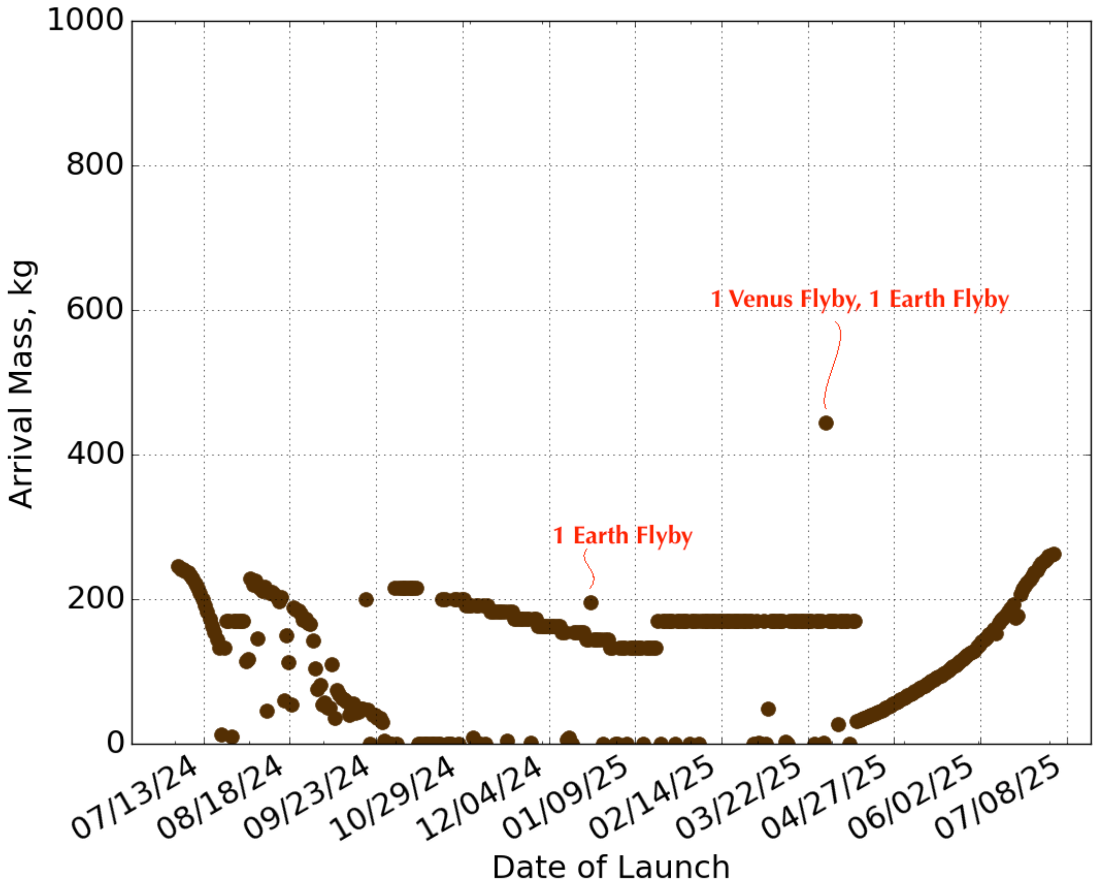


CASE STUDY 1 – URANUS MISSION

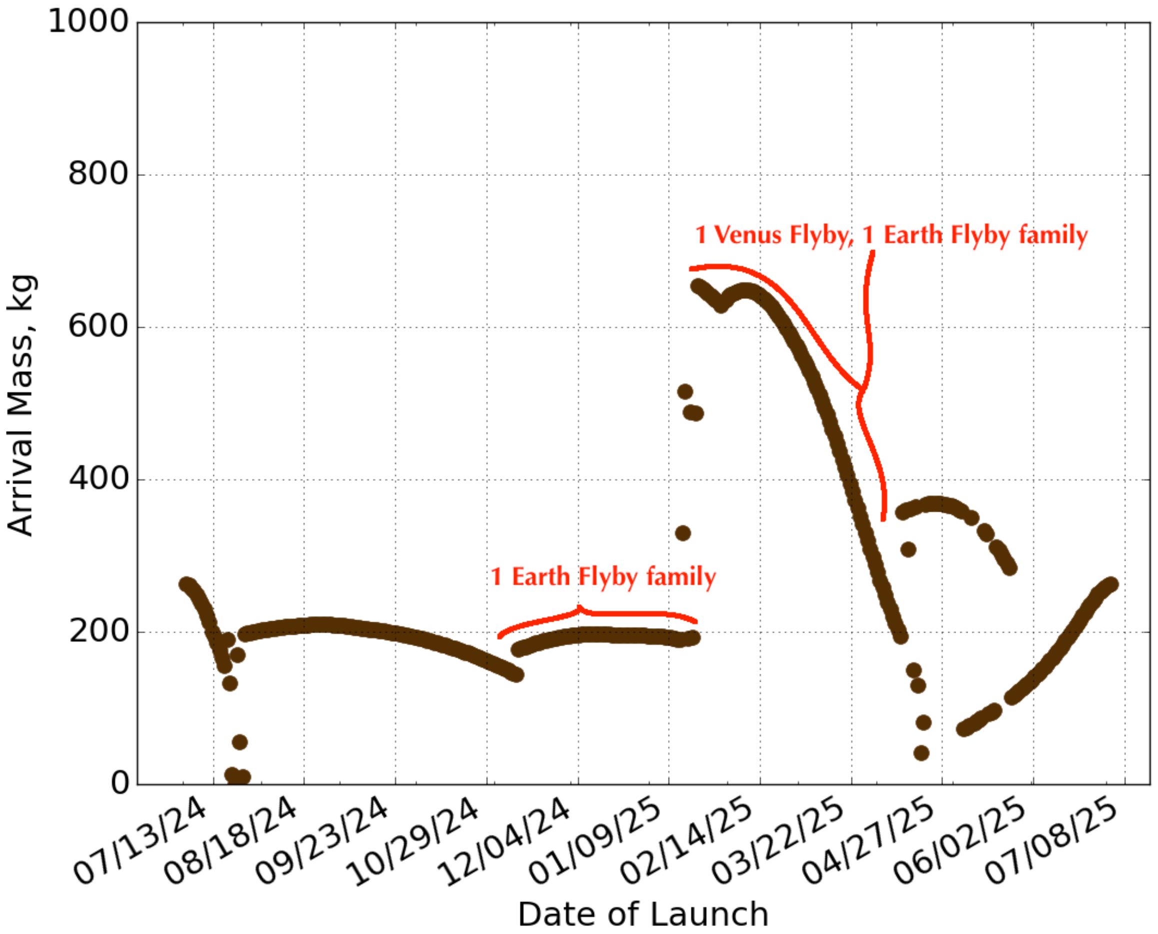


CASE STUDY 1 – URANUS MISSION

- Iteration 2

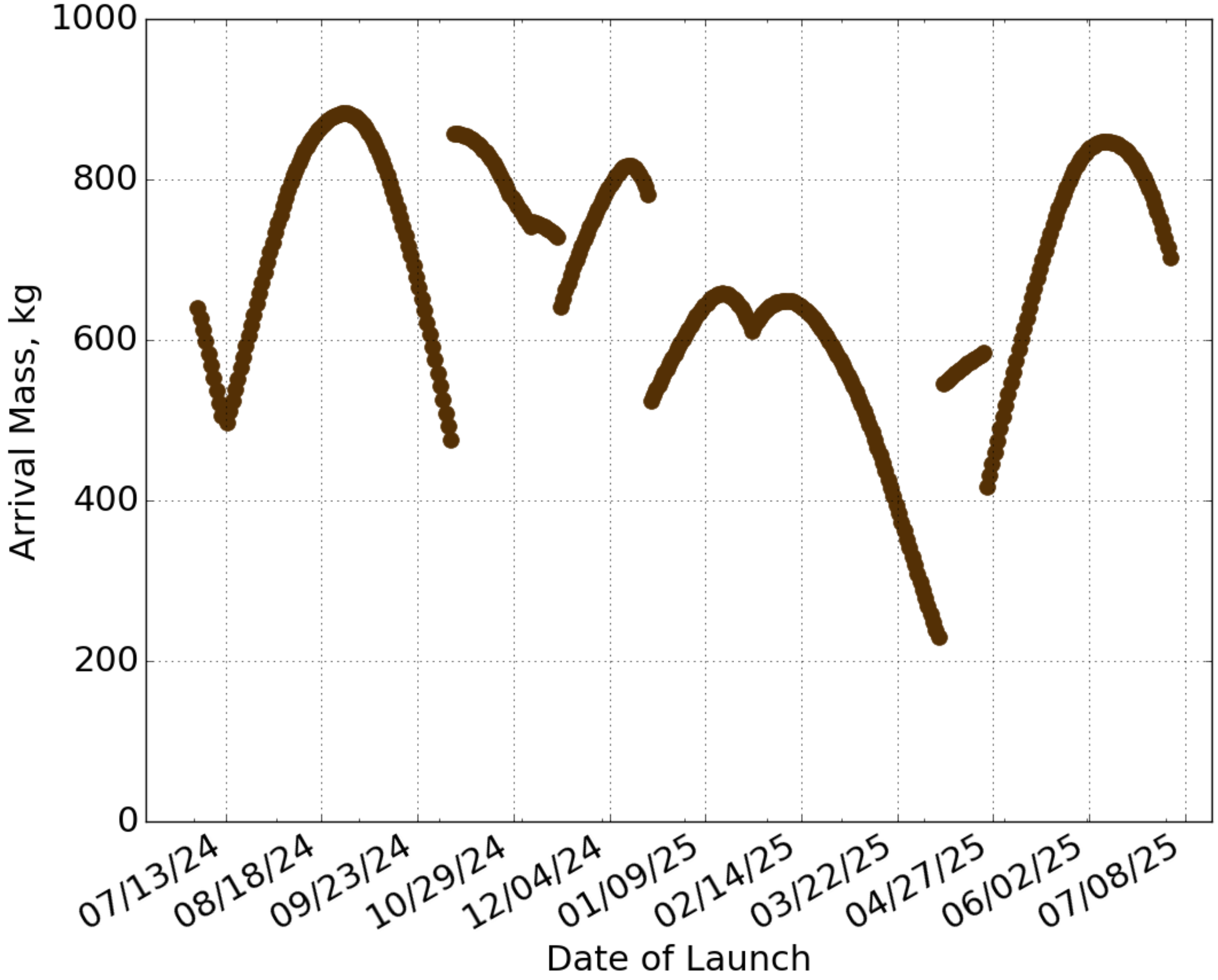


- Iteration 10



CASE STUDY 1 – URANUS MISSION

- Iteration 80



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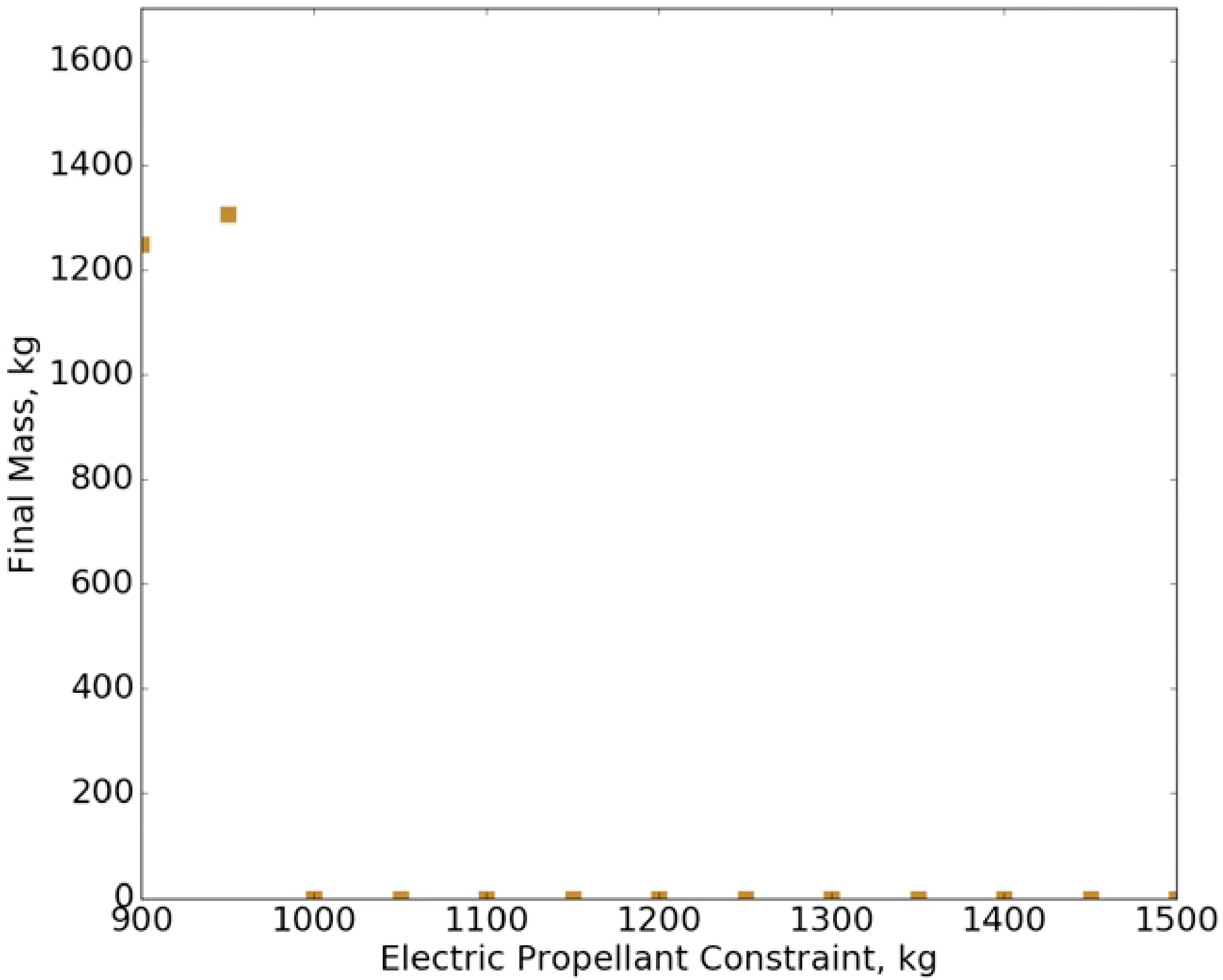
CASE STUDY 2 – LOW-THRUST ASTEROID SAMPLE RETURN

- Goal: quantify design space for return of a sample from asteroid 1949TG Daphne (ecc > .2, inclination > 10 deg)
- Launch sometime in late 2024 or early 2025
- Required 12 minutes of human labor for setup and 32 wall clock-minutes of computation time on a 64 core server

Mission Parameters	
Propulsion model	polynomial thrust, mass flow rate vs. power available
Propulsion system	2 NEXT engines[7)]
Maximum flight time	10 years
Earth return velocity	< 10 km/s
Duty cycle	90%
Propellant margin	10%
Power margin	15%
Bus power	1 kW
Stay time	> 500 days
EMTG run-time per iteration	20 seconds
Low-thrust transcription	Finite Burn[8)]
PEATSA Options	
run_type	trade study
comparison_criteria	maximum final mass
wait_for_guess	yes
flyby_bodies	none
options_to_vary	launch vehicle; solar array size; electric propellant load
option_ranges	Atlas V - 401 (0), 411 (1), 421 (2), 431 (3), 541 (9) or 551(10); 20 to 40 kW; 900 to 1500 kg
trade_study_type	vary each option separately

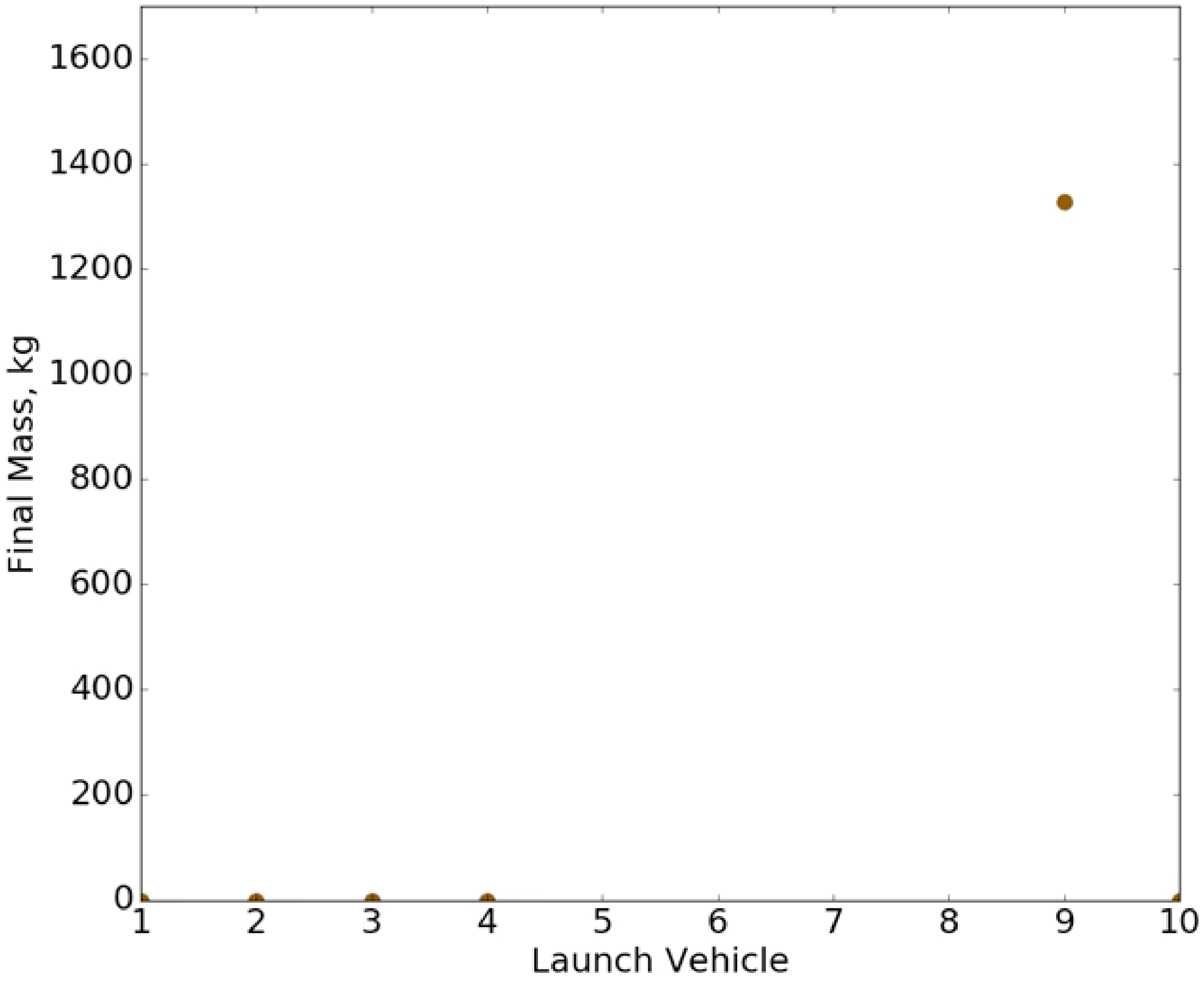
CASE STUDY 1 – URANUS MISSION

- Electric Propellant Tank Sizing



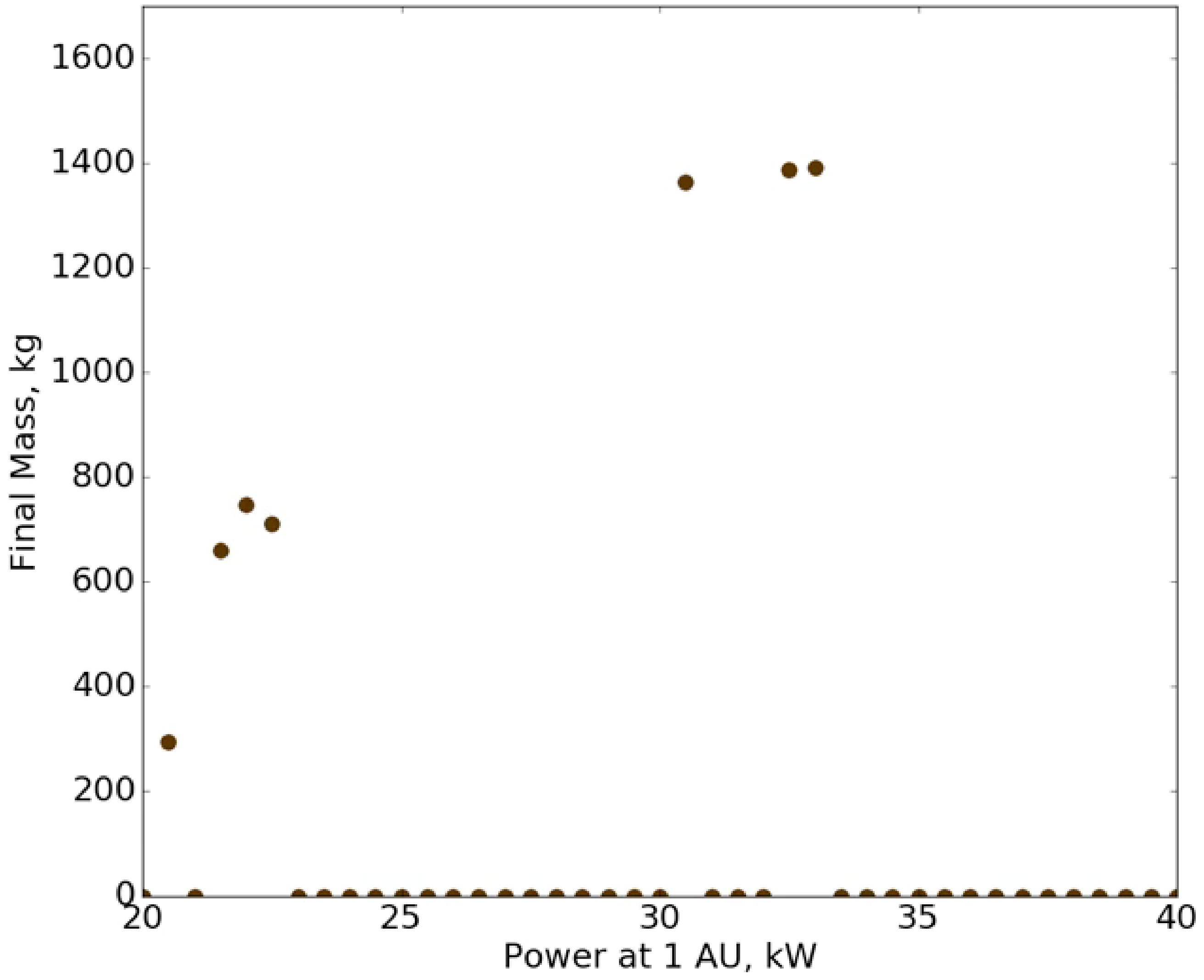
CASE STUDY 1 – URANUS MISSION

- Launch vehicle selection
  - 1 = Atlas V 401
  - 2 = Atlas V 411
  - 3 = Atlas V 421
  - 4 = Atlas V 431
  - 9 = Atlas V 541
  - 10 = Atlas V 551

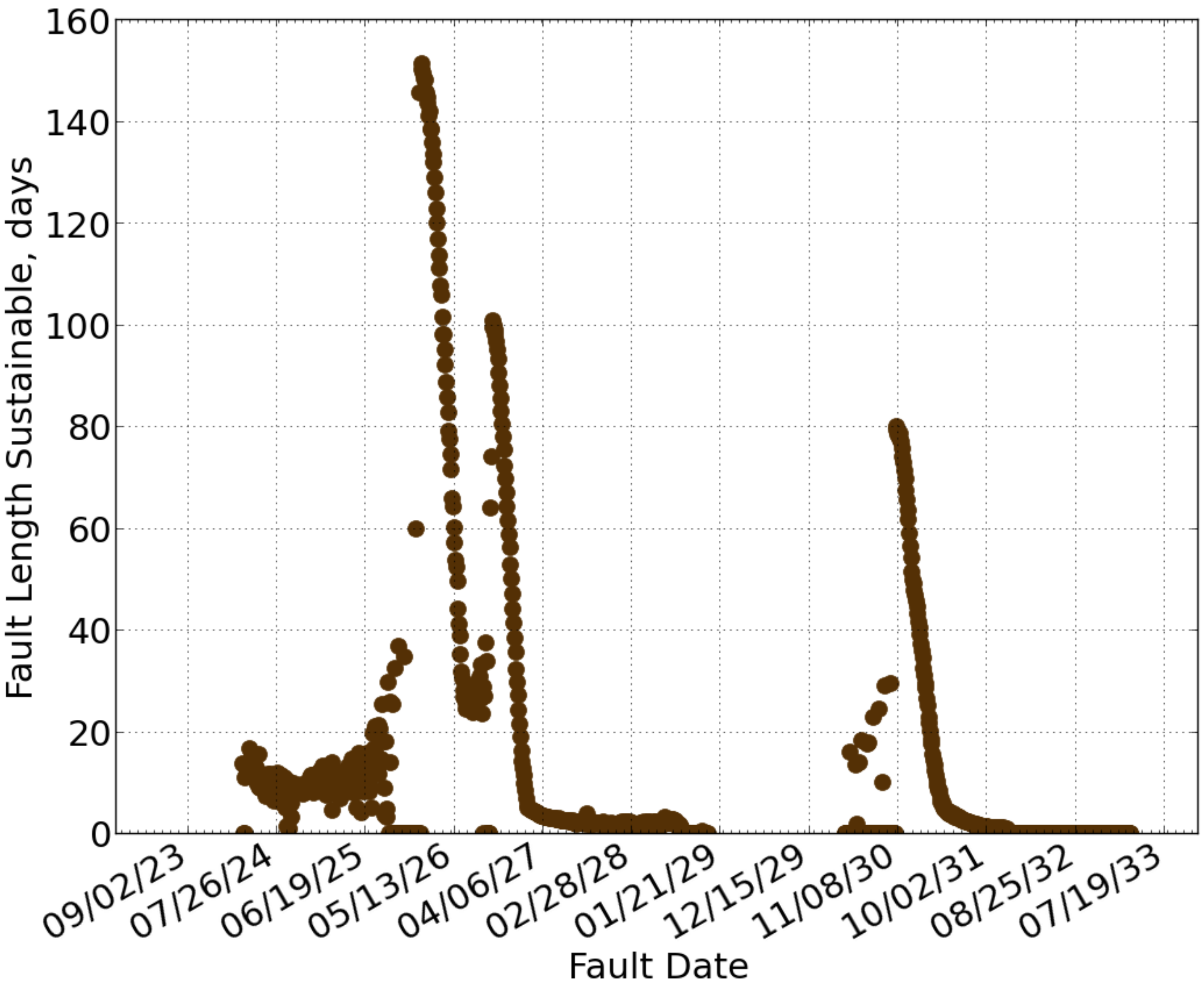


CASE STUDY 1 – URANUS MISSION

- Solar Array Sizing



MISSED-THRUST



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SUMMARY

- Sensitivity analysis is no longer a task that requires significant hands-on time for mission designer
- PEATSA allows simplified viewing of trade study effects, missed maneuver planning, etc.
- Overall computation time decreases greatly, because individual runtime decreases
- PEATSA increases global optimization capability