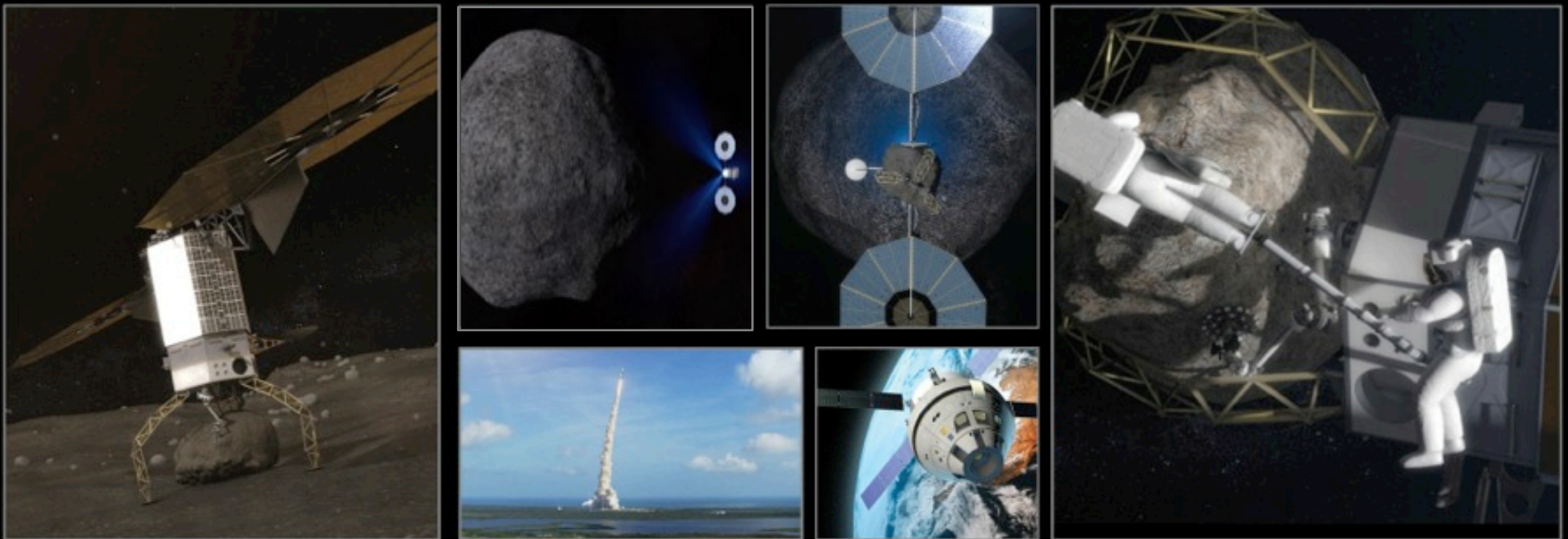




SENSITIVITY OF THE ASTEROID REDIRECT ROBOTIC MISSION (ARRM) TO LAUNCH DATE AND ASTEROID STAY TIME

**Melissa L. McGuire, Laura M. Burke, Steven L. McCarty,
Nathan J. Strange, Min Qu, Haijun Shen, and Matthew A. Vavrina**

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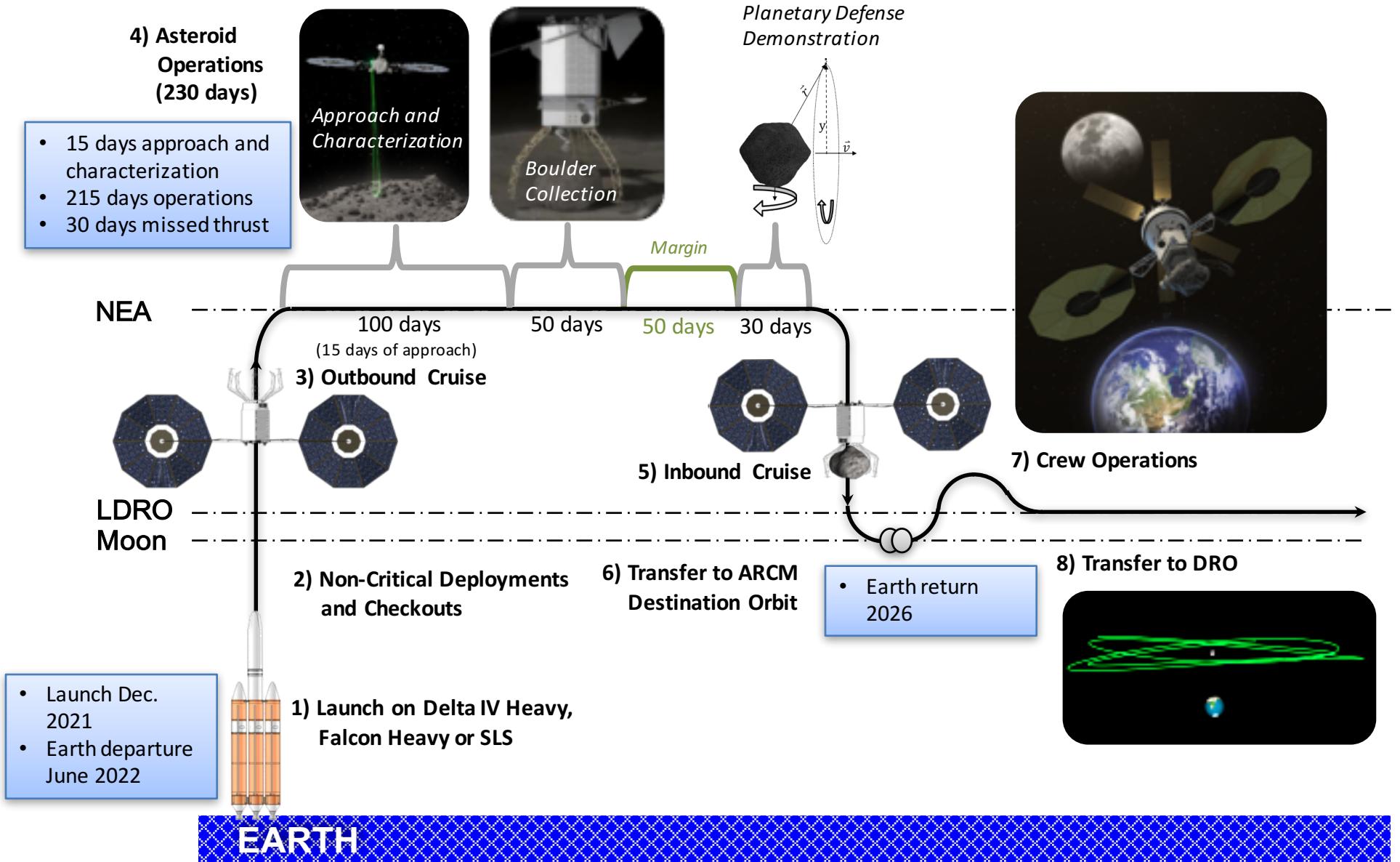


Outline



- **Current ARRM Reference Mission**
- **ARRM vehicle description**
- **Synodic period of Earth and 2008 EV5**
- **Reference Trajectory Launch Date sensitivity**
- **Asteroid Stay Time sensitivity**
 - Asteroid mass vs. stay time
 - Spacecraft mass vs. stay time
- **Contours of Asteroid mass and Spacecraft dry mass vs. Stay time**
- **Conclusions**

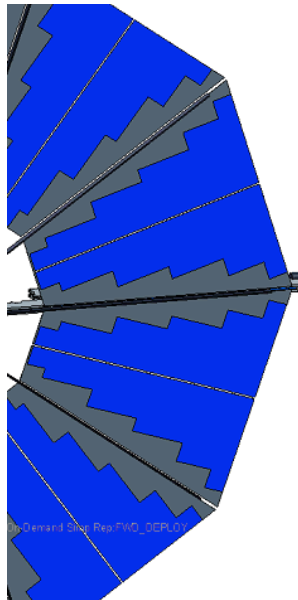
Current Asteroid Redirect Robotic Mission (ARRM) Reference



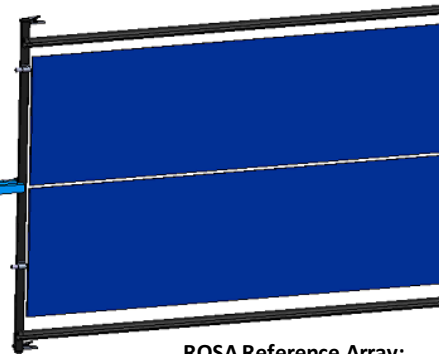
Asteroid Redirect Vehicle (ARV)



MegaFlex Reference Array:
~20 m wing tip to base

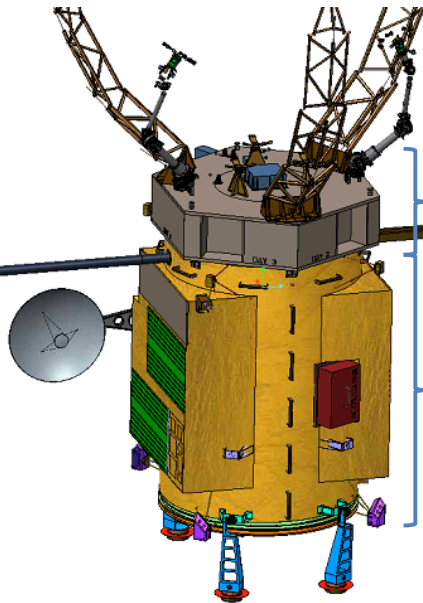


Capture Module:
Hosts functions for capturing Boulder



ROSA Reference Array:
~25 m wing tip to base

Spacecraft Bus:
(provider TBD)
Hosts core spacecraft housekeeping functions, GN&C, and Ion Propulsion System



EP system specifications	Value
EOL Power to PPU at 1AU	42 kW
No. thruster strings	3+1
EP duty cycle	90%
Dry mass assumed	5000 kg
Useable Xe mass	5000 kg
Xe margin	6%
Hydrazine propellant mass	400 kg

ARV Government Reference Design

Asteroid Redirect Vehicle (ARV) and would be composed of a contractor-provided spacecraft bus, a NASA-provided capture module (CAPM), and a NASA-provided Hall thrusters and their corresponding Power Processor Units (PPUs) which would be integrated to the Ion Propulsion Subsystem on the spacecraft by the spacecraft vendor

Current Reference Asteroid Target



December of 2023, is the closest that 2008 EV₅ and the Earth will be in the near term

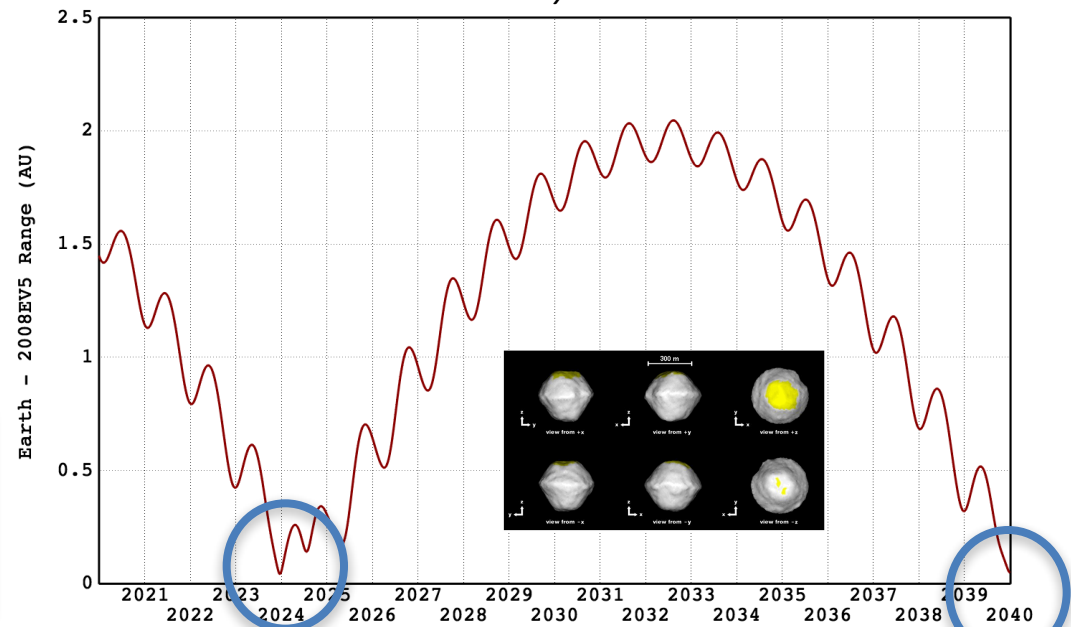
- Synodic Period of the Earth and 2008 EV₅ is 15.7 years
- Proposed ARRM reference mission targeting operations during this closest approach to Earth in late 2023/early 2024
- Asteroid operations planned during close approach to allow for observation from Earth of Planetary Defense Demonstration

The closest approach between Earth and 2008 EV₅ will not repeat again until after 2040.

2008 EV5 Close Approach Data

Date	Minimum Distance (AU)	V-relative (km/s)
2010-Apr-18	0.2397	9.460
2022-Dec-27	0.4236	16.055
2023-Dec-20	0.0422	5.345
2024-Jul-20	0.1410	4.9456
2025-Apr-27	0.1746	7.4511
2038-Dec-23	0.3198	12.922

Data From JPL Small Body Database Browser

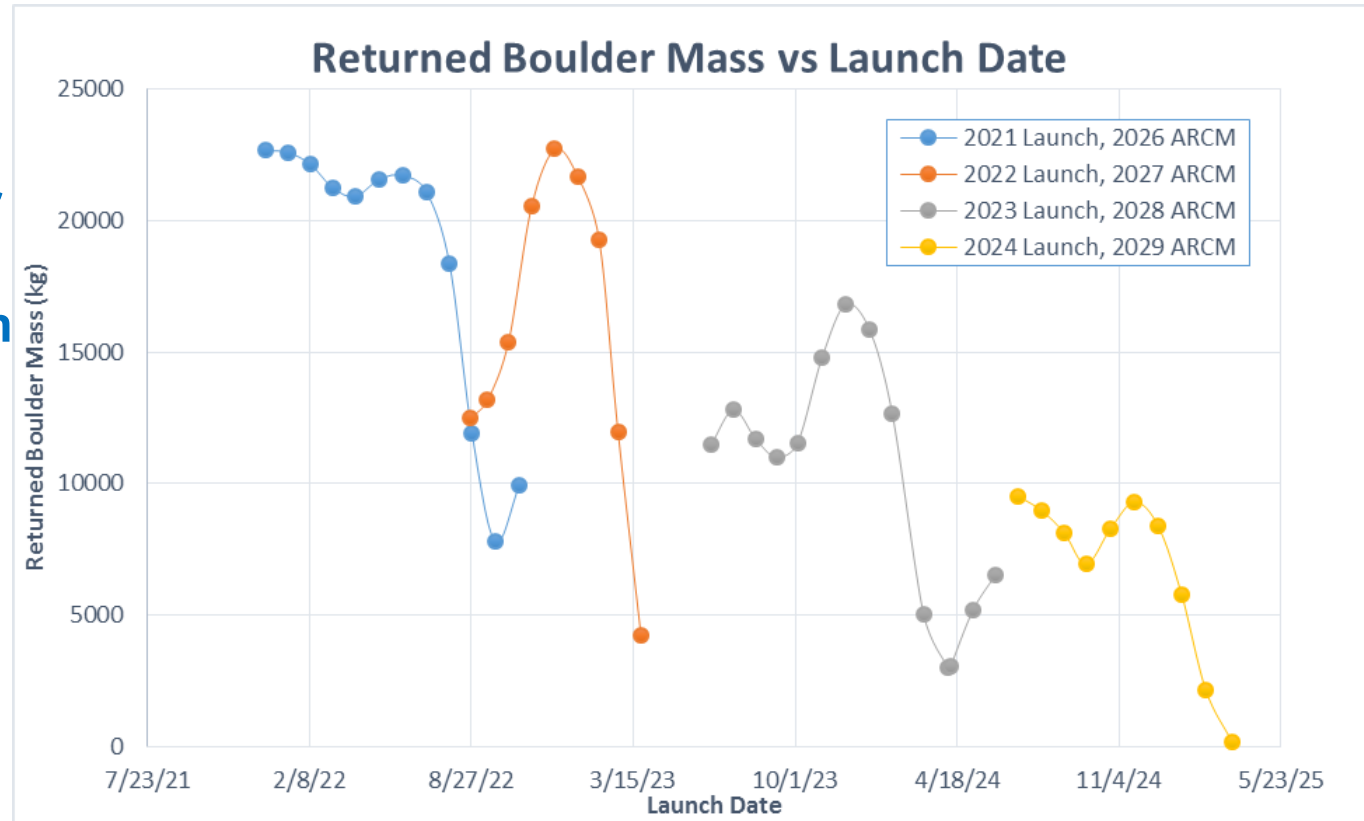


Earth-2008 EV5 Range from 2020-2040

Reference Trajectory Launch Date Sensitivity



- Any change in launch date will impact either the allowable spacecraft dry mass or the returned boulder mass capability or both
- Reference launch date December 2021, return date no later than Dec 2026
- Departure leg targets series of lunar flybys
- Launch date slips must coordinate with availability of the moon (28 day intervals)
- Families of Launch date/arrival date pairs investigated

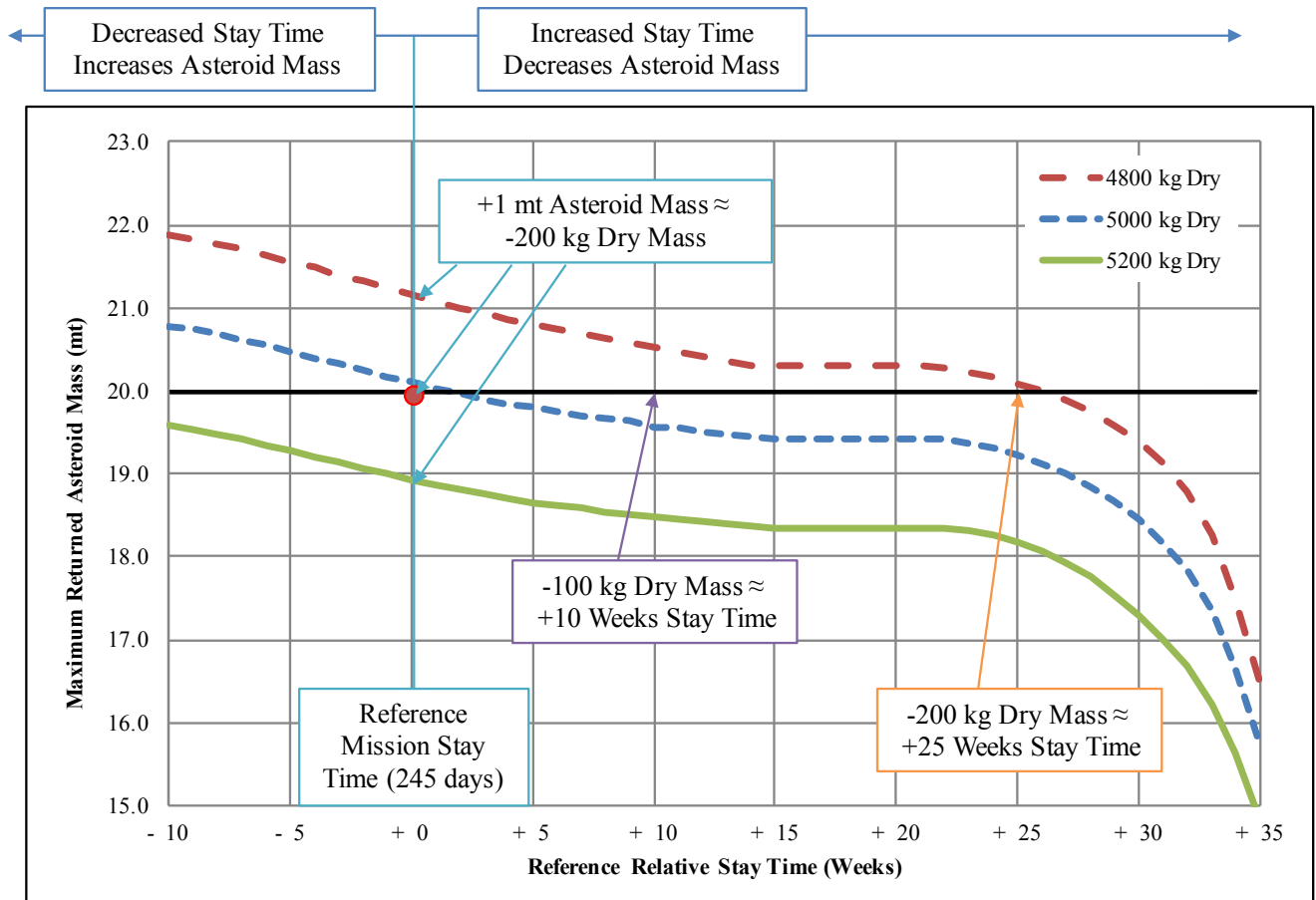


Launch dates delays (and subsequently Earth departure dates) further out from the current reference date, the orbital alignment between Earth and 2008 EV5 becomes less optimal, driving the trajectory Delta-V (ΔV) requirements and decreasing the asteroidal boulder mass return capability

Maximum Asteroid mass vs Asteroid stay time



- Stay time increase **+25 weeks (total 420 days)** could still return **20 t asteroid mass**.
- Reference trajectory allocates 245 days at the asteroid:
- Vary stay time at asteroid -10 weeks to +35 weeks
- Curves of constant spacecraft dry mass
- Maximized returned asteroid mass
- After reference + 25 weeks, planetary alignment and coast periods on return leg used, asteroid returned mass sharply decreases

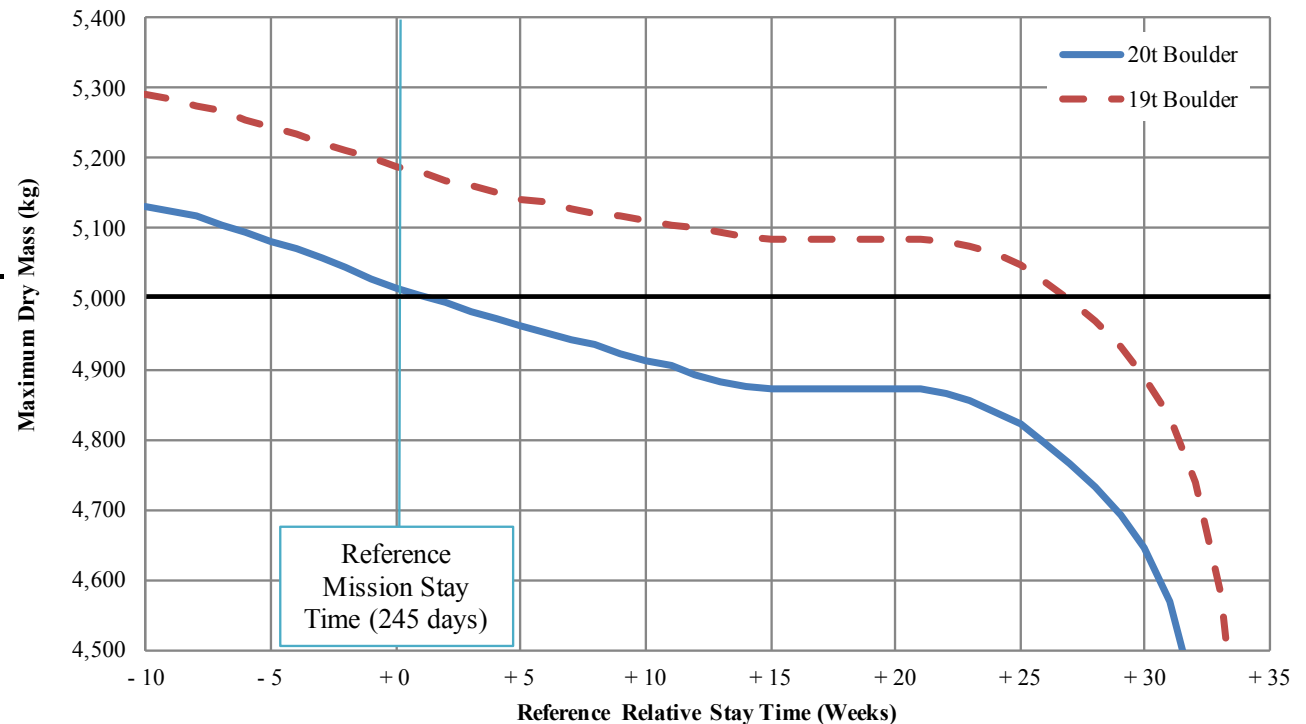


Can increase stay time +25 weeks (total 420 days) and still return 20 t asteroid mass at reduced ARV mass. As the stay time increases beyond +25 weeks, an exponential decline in maximum returned mass is observed.

Maximum ARV mass vs Asteroid stay time



- ARV dry mass sensitivity demonstrates similar characteristics for the returned asteroid mass curve .
- Vary stay time at asteroid - 10 weeks to +35 weeks
- Curves of constant boulder mass
- Maximized ARV mass
- From -10 weeks to +15 weeks relative to the reference, the slope is approximately -10 kg/week
- **Stay time +25 weeks, results in an exponential decline in maximum ARV dry mass**

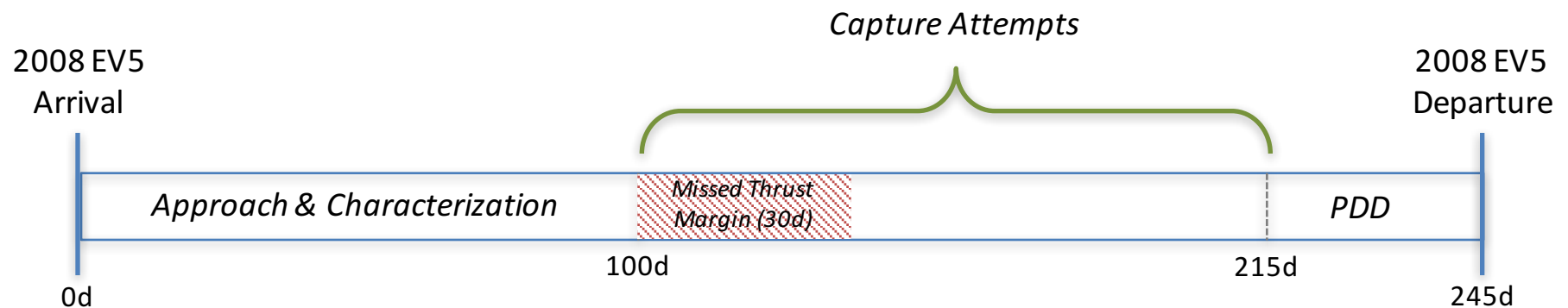


Can increase stay time +25 weeks (total 420 days) and still fly 5000 kg ARV but must reduce to return 19t asteroid mass. As the stay time increases beyond +25 weeks, an exponential decline in maximum ARV mass is observed.

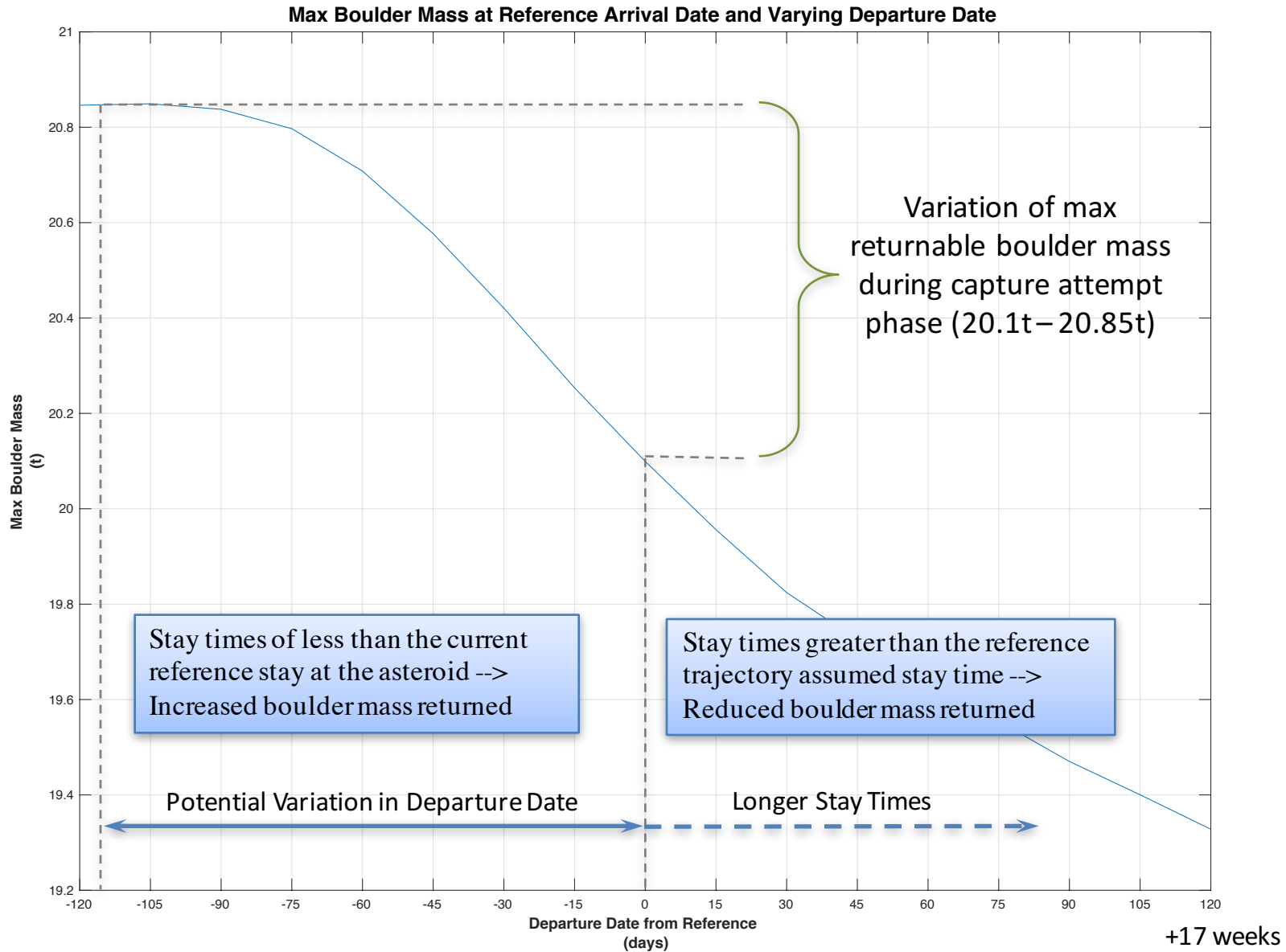
Event Timeline during Asteroid Stay



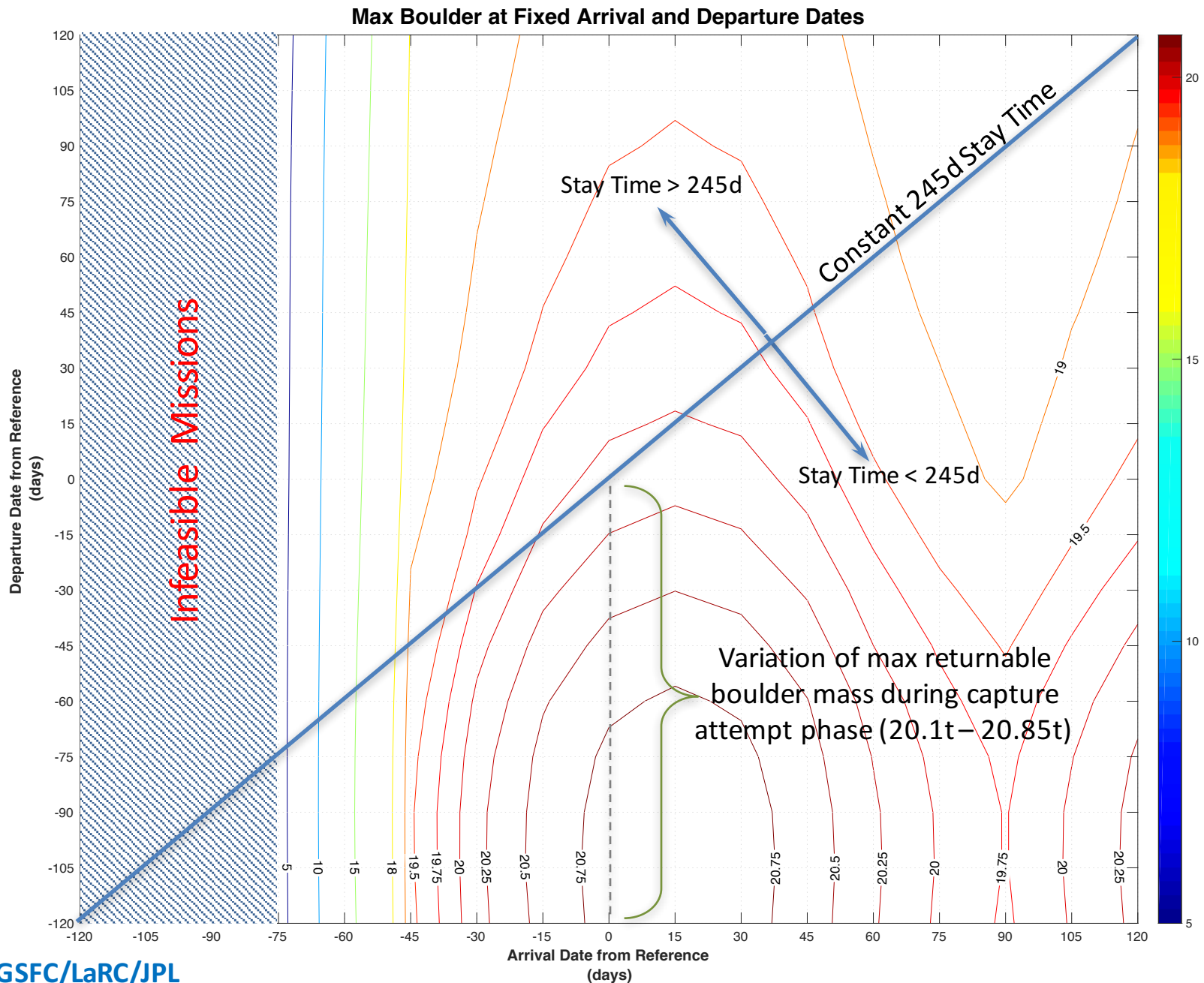
- Capture attempt period can be up to 115 days depending on the amount missed thrust margin used
- Assuming 2008 EV5 Departure date can occur up to 115 earlier than reference departure date if successful 1st capture attempt and immediate transition into PDD phase



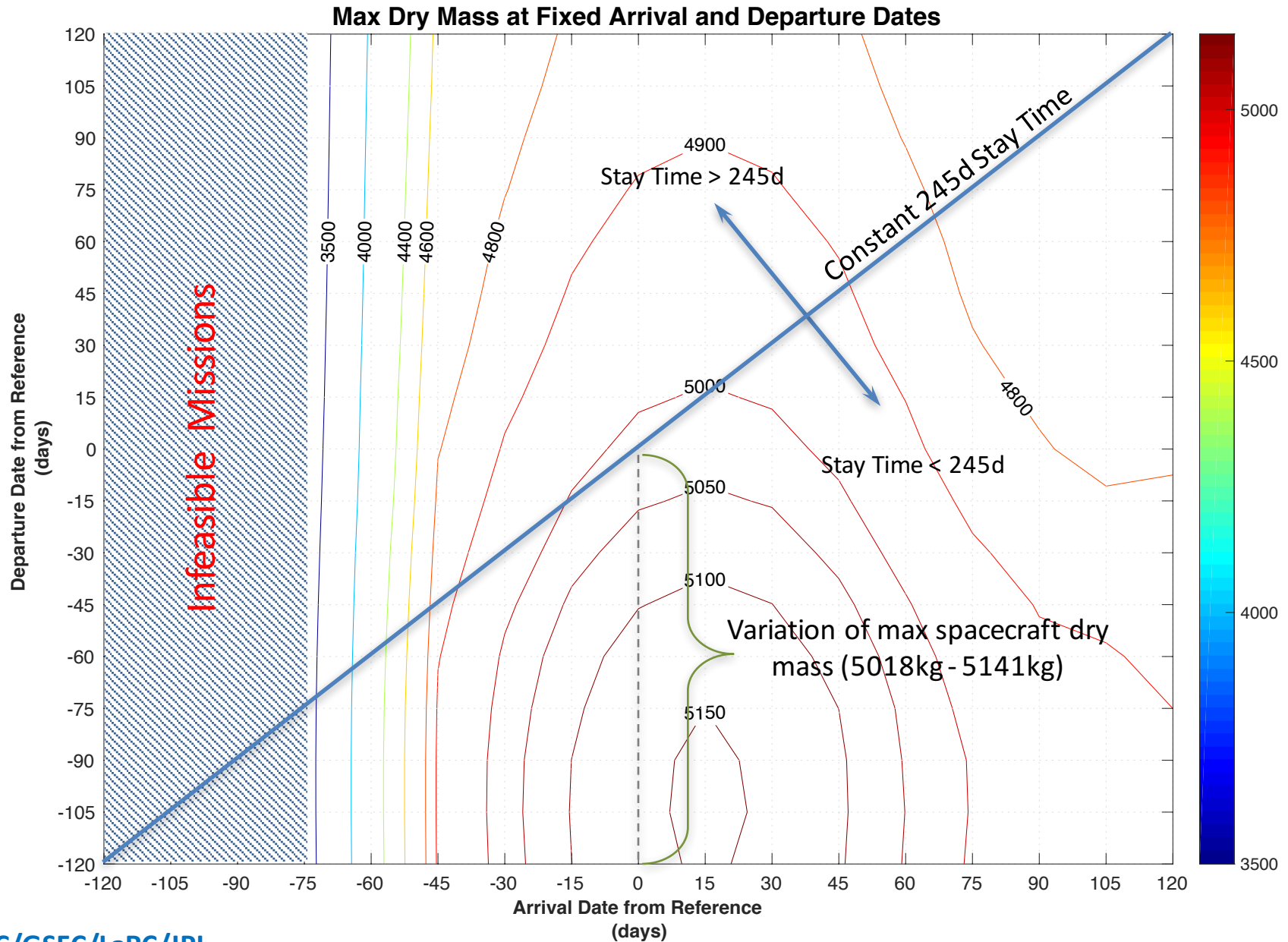
Max Boulder vs 2008 EV5 Departure Date



Maximum Boulder at Fixed Arrival and Departure Dates



Maximum Spacecraft Dry Mass at Fixed Arrival and Departure Dates



Conclusion



- **The current timeline for the proposed Asteroid Redirect Robotic Mission (ARRM) is the optimal time to bring back as much asteroid mass as possible from 2008 EV₅ given the assumed high power SEP in space propulsion system in the near term.**
- Due to synodic period of Earth and 2008 EV₅, December of 2023, is the closest that 2008 EV₅ and the Earth will be until 2040
- Delays in the launch and Earth return dates will result in a capability for less asteroid mass returned
 - Launch dates delays (and subsequently Earth departure dates) from the current reference date, the orbital alignment between Earth and 2008 EV₅ becomes less optimal, driving the trajectory Delta-V (ΔV) requirements and decreasing the asteroidal boulder mass return capability

Launch date delays of a few years, and a subsequent a one for one Earth return delay are still feasible missions at the cost of returned asteroid mass.

Asteroid stay time can be increased from the current reference trajectory assumptions by either reducing the amount of asteroid mass returned, the dry mass of the spacecraft or both.