Metrics and Models for Gravity Tractor Demonstation Missions and Deflections

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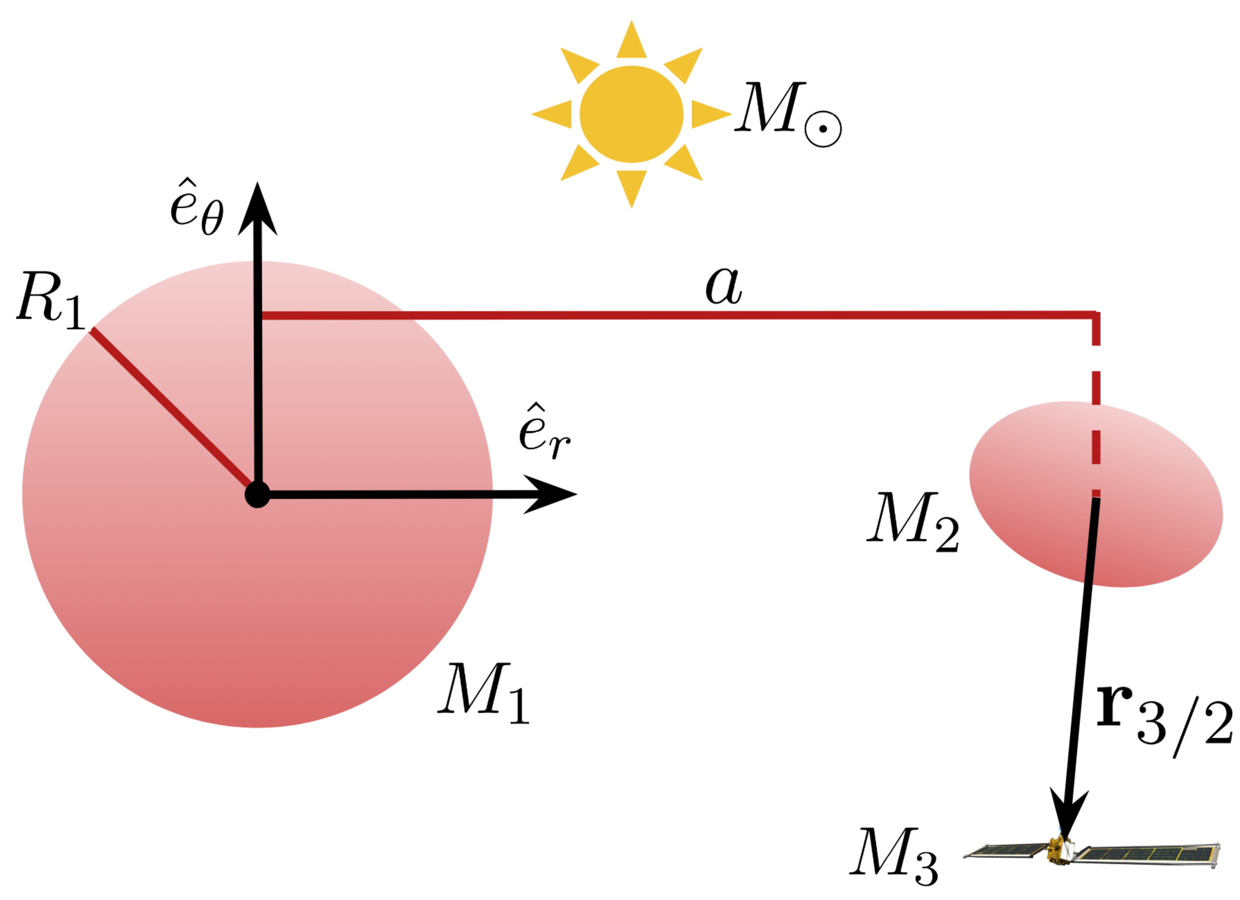
Motivation
Asteroids cause destructive impacts to Earth

Requirement
Demonstrate all hazard mitigation technologies (ex: DART [1])

Questions
(1) What are the easiest/hardest bodies to deflect with a GT?
(2) How does a demo mission relate to a real deflection scenario?
(3) How can you induce the fastest change to the state of an asteroid?
(4) How can you maximize the change to an asteroid's state?

Introduction
After the success of the NASA/DART mission [1], attention has turned to demonstrating alternative technologies for mitigation and deflection. The gravity tractor (GT) is one such technology that uses its own gravity to slowly “tow” an asteroid and alter its trajectory [2].

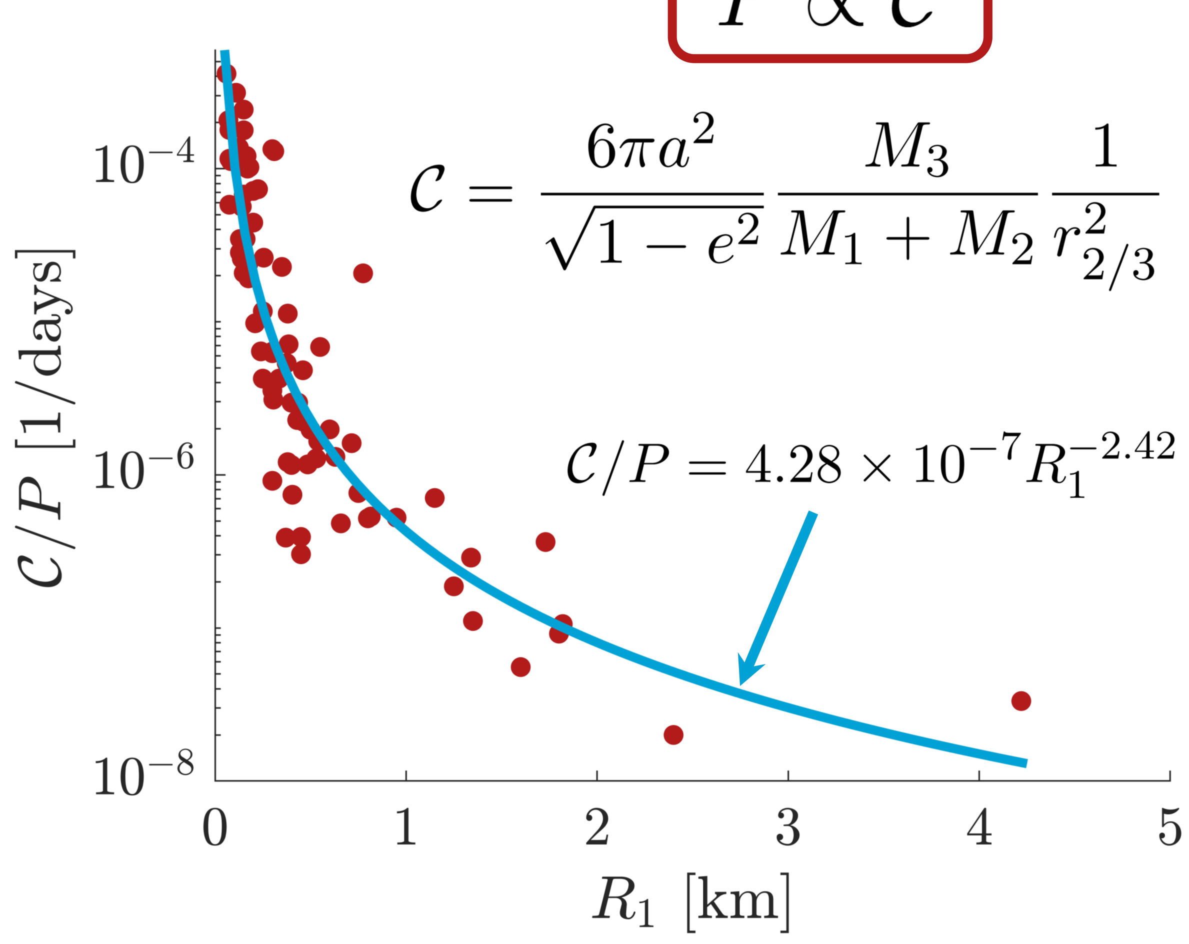


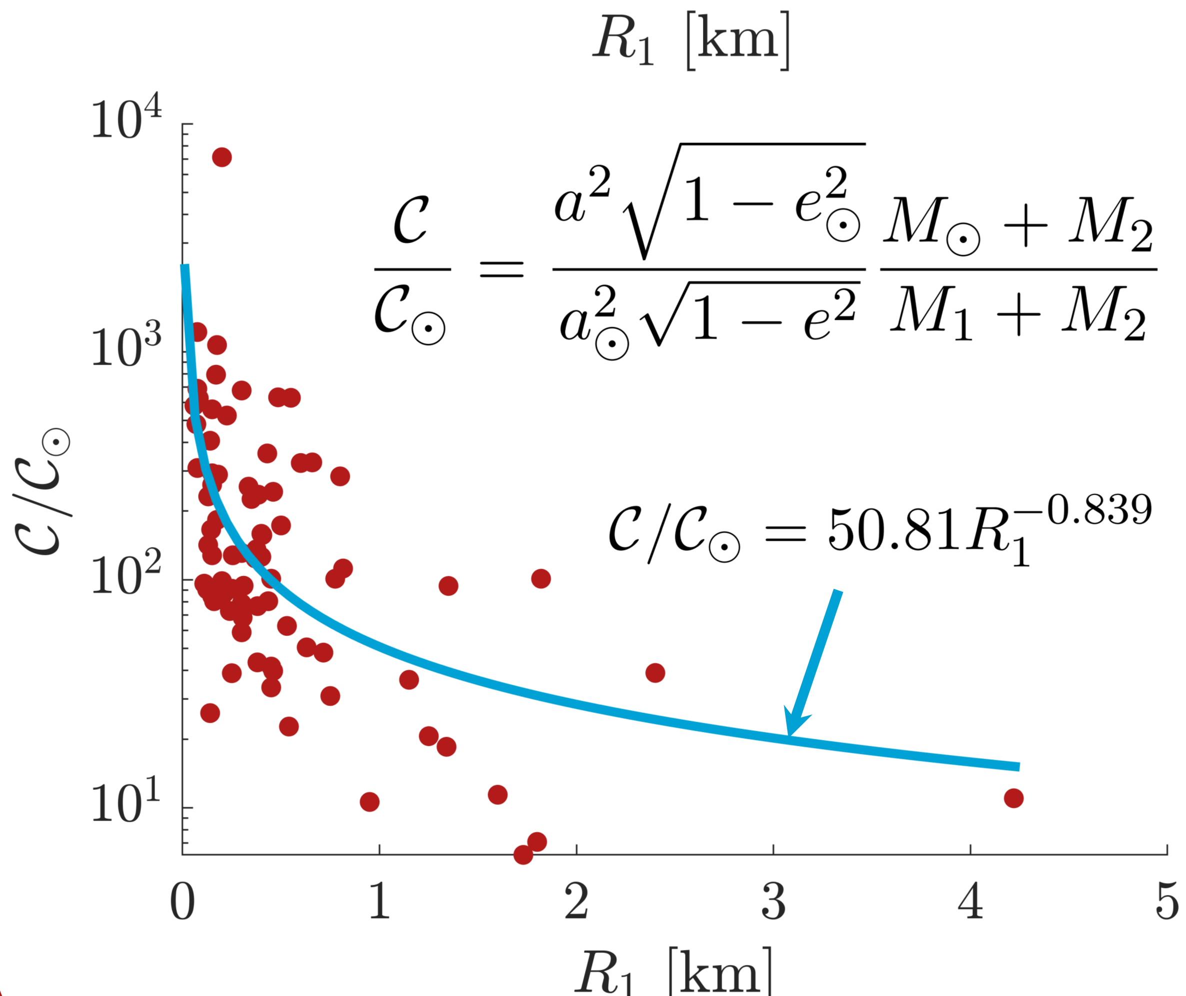
2020 AZ2 System Parameters
- M_1 = 3.5E+9 kg
- M_2 = 5.1E+8 kg
- R_1 = 70 m
- R_2 = 37 m
- a = 348 m
- ρ = 2400 kg/m³ (assumed)
- P = 22 hours

GT Spacecraft Parameters
- M_3 = 1500 kg
- I_{sp} = 1730 sec
- Plume Angle = 20 deg

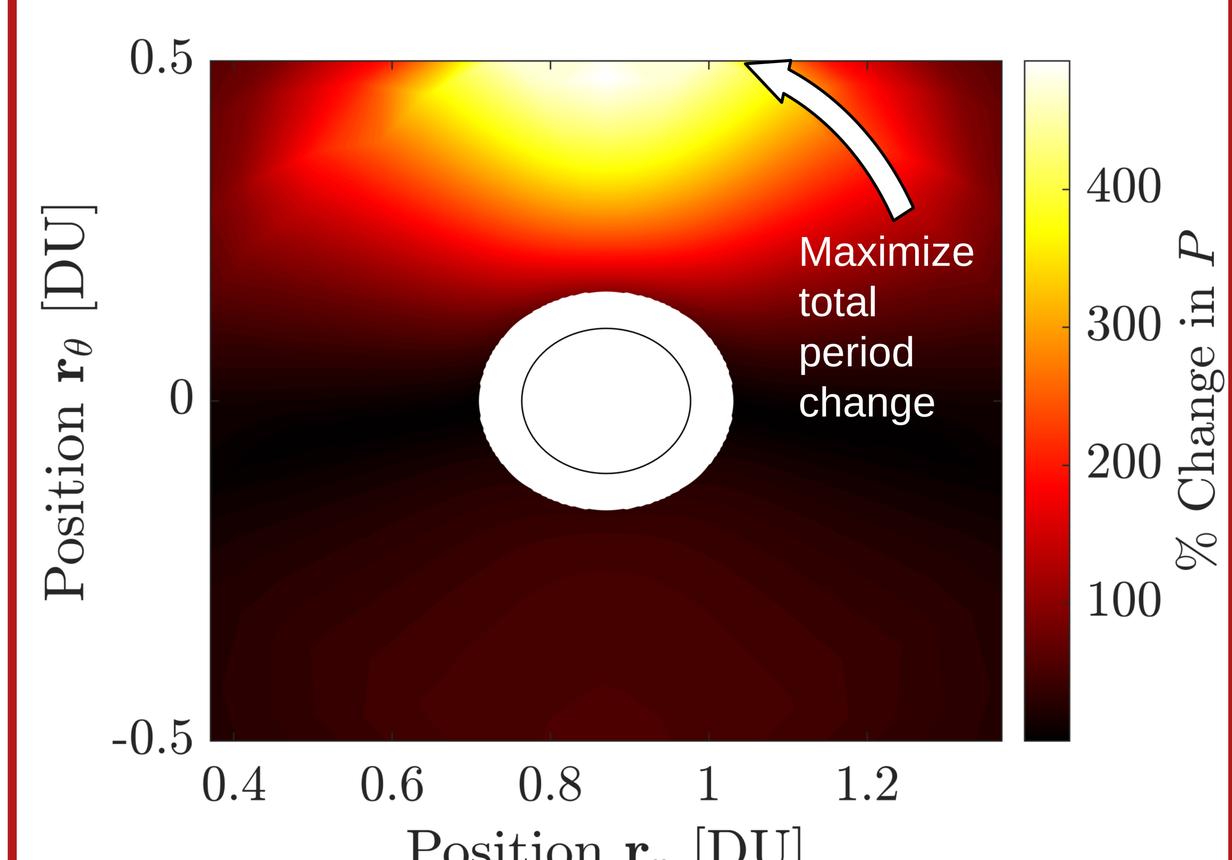
A: Metric for GT Effectiveness
- Directly compare heliocentric vs system changes
- Metric (C) is amplitude of change to period (P)

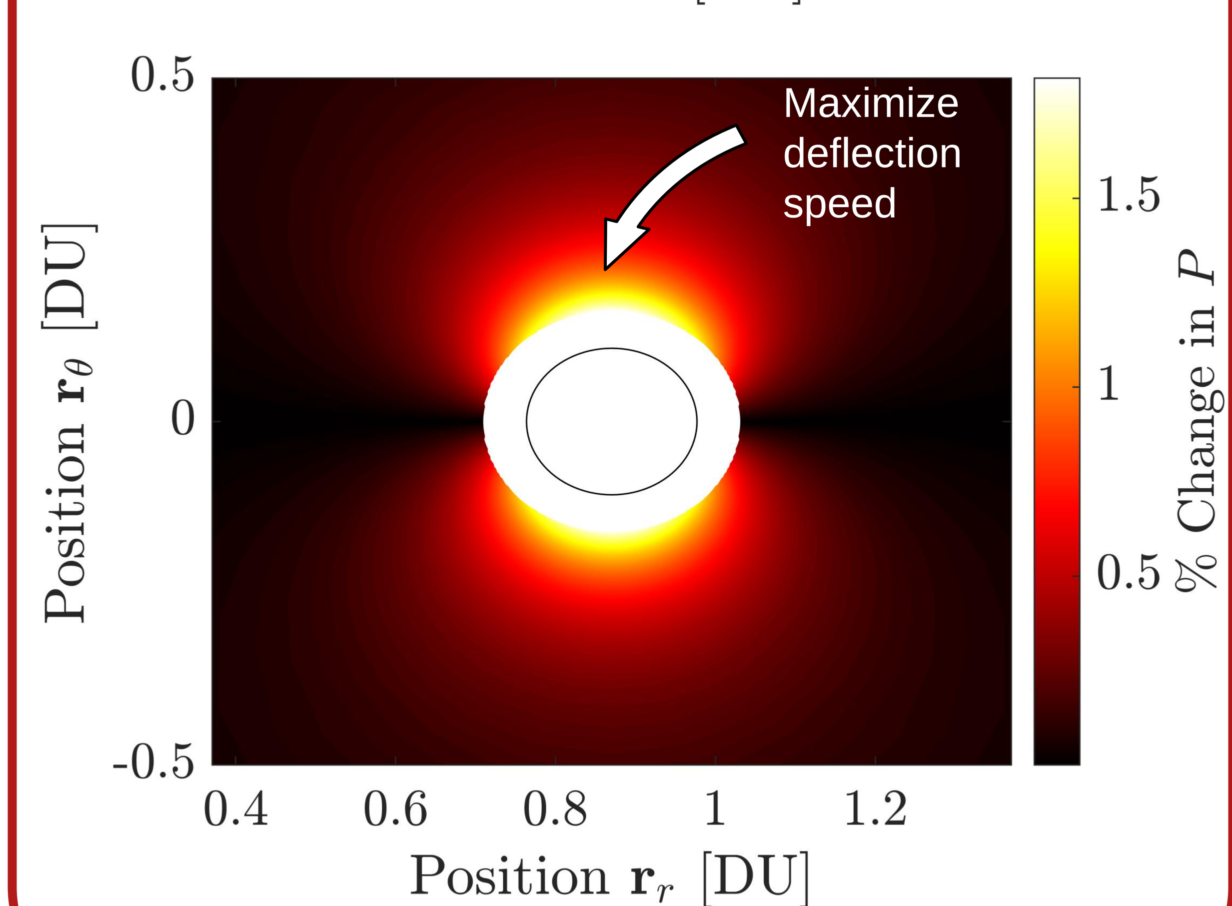
$$\dot{P} \propto \mathcal{C}$$



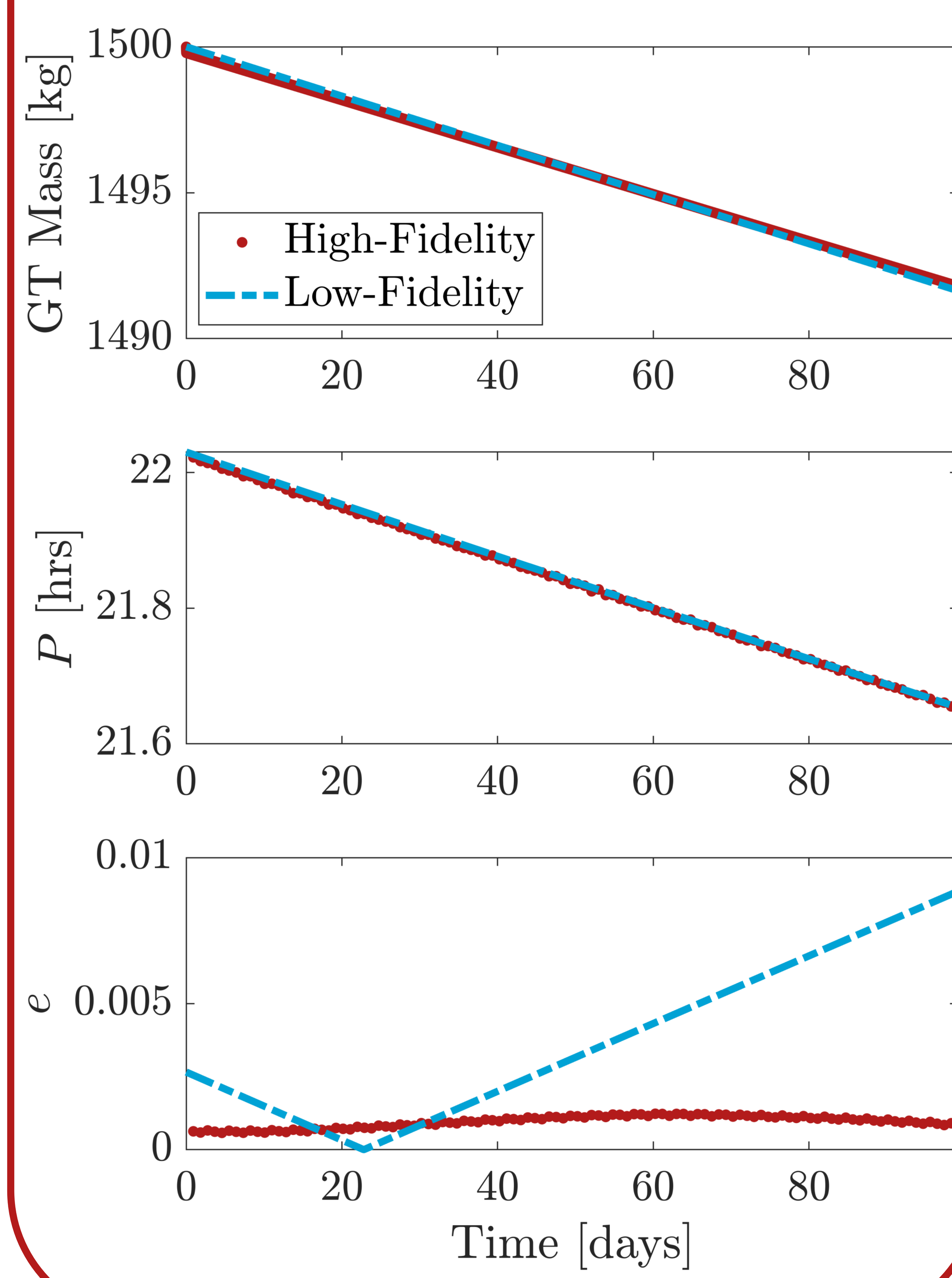


B: Low-Fidelity Model Phase Space Exploration
- Analytical approximation of control effort for GT
- Keplerian dynamics + GT perturbation
- Gauss planetary equations





C: High-Fidelity Model of a GT in a Binary System
- Closed-loop controller around GT
- Spherical primary and ellipsoidal secondary expanded to second order
- SRP cannonball model with eclipsing
- Solar gravity perturbation



Conclusions
A.1: The C metric can be used to predict GT effectiveness for a target and relates demos to deflections

A.2: It is easier to induce changes to a moonlet than a single asteroid

B.1: The hovering position that maximizes ΔP is not the same position that changes period the fastest

C.1: The low-fidelity model is viable for trade-space mission design

C.2: The high-fidelity model should be used for mission planning purposes [3]

References and Acknowledgements

[1] Chabot et al., (2024) *PSJ*
[2] Lu and Love, (2005) *Nature*
[3] Ballouz et al., (2025) *This Conference*

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