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APPLIED PHYSICS LABORATORY

IAA-PDC-23-00-015 Hypothetical Asteroid 2023 PDC Mass Measurement via Doppler Gravimetry in a Reconnaissance Flyby

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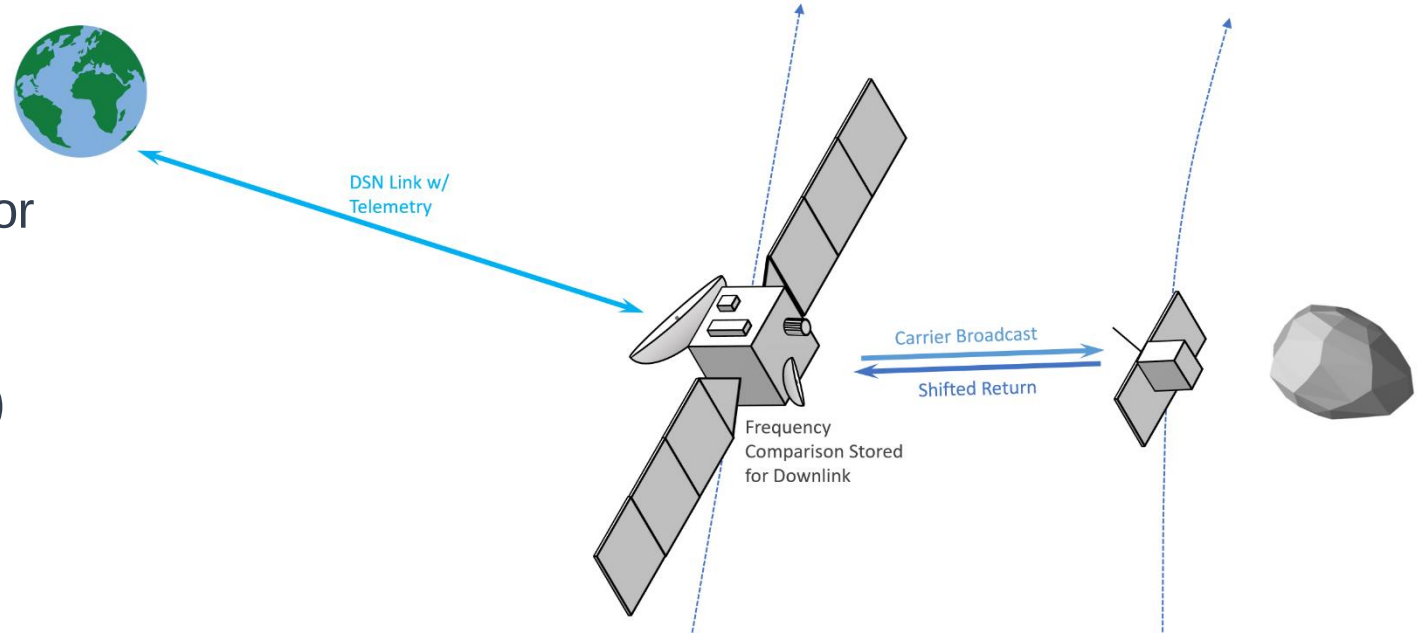
Motivation

- Knowledge of a potentially hazardous asteroid's (PHA's) mass and porosity is critical to predicting impact consequences and/or to plan a mitigation
  - Total kinetic energy of impact, energy lost to the atmosphere, impact effects
  - Momentum required for deflection, effectiveness of deflection, likelihood of disruption
- Only current practical method to measure mass of small PHAs is spacecraft rendezvous
- Highly desirable to be able to measure the mass using a spacecraft flyby
  - More frequent launch opportunities
  - Can arrive at a PHA quicker vs a rendezvous mission

Doppler Gravimetry

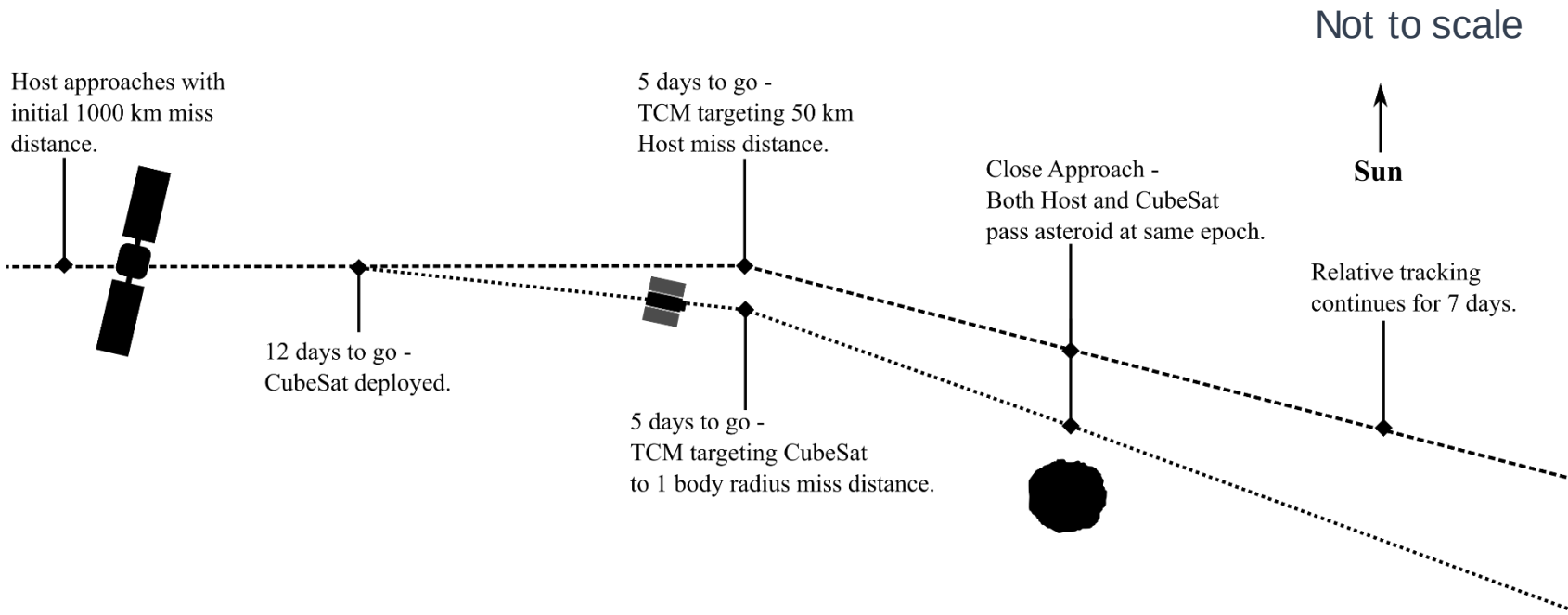


- Augment the flyby satellite with one or more deployable CubeSat test-masses
- Host spacecraft tracks test-mass(es) using optical and RF measurements (Doppler and range)
- Test-masses pass by asteroid much closer than the host spacecraft
- More sensitive than the optical-only method (OpGrav)
  - Christensen et al. showed that the mass of <100 m diameter asteroids is measureable if instrument has GRAIL-like Doppler precision
- CubeSat implementation trades some precision for simpler implementation
  - S-band TT&C transponder onboard the CubeSat turns around signal transmitted by host
  - Host compares transmitted frequency and waveform to what is received from the CubeSat to compute Doppler and range
  - Measurement accuracy of < 0.1 mm/s velocity and < 10 m range

Christensen, Lukas, Park, Ryan, Bell, James, 2021. Estimating Asteroid Mass from Optically Tracked Radio Beacons. Journal of Spacecraft and Rockets. https://doi.org/10.2514/1.A34830

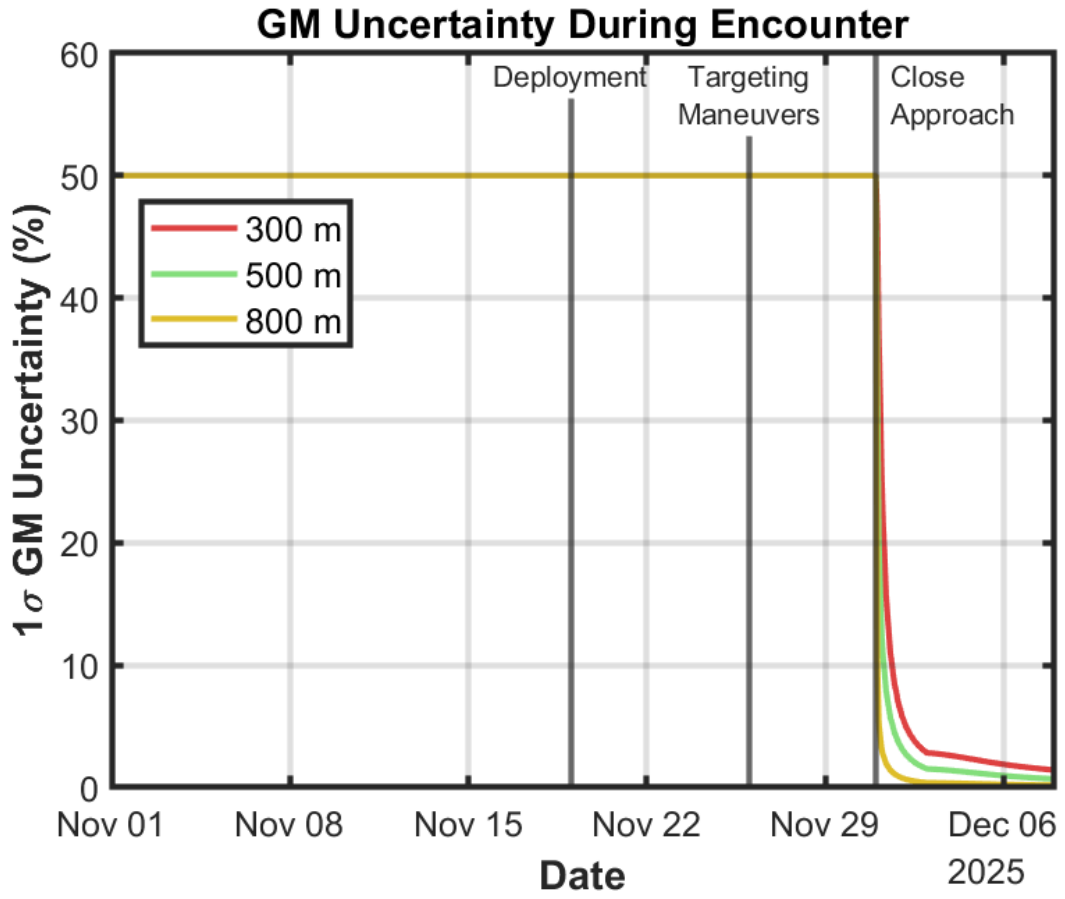
2023 Exercise Scenario

- At time of discovery, 2023 PDC has a most likely size range of 220 – 660 m diameter
  - Probably too small for OpGrav, but good candidate for DopGrav
- Reconnaissance flyby mission launched in October 2024 with asteroid close approach 01 December 2025
  - Relative velocity of 1.7 km/s
- Spacecraft assumptions
  - Small-sat host spacecraft with LORRI/DRACO-like imager
  - 6U CubeSat test-mass with on-board propulsion (similar to LICIACube)
- Host initially targets 1000 km close approach (C/A) distance
- Timeline:
  - C/A – 15 days: optical navigation images to the asteroid begin
  - C/A – 12 days: test-mass is deployed
  - C/A – 5 days: both spacecraft maneuver to target final C/A distances
  - C/A + 7 days: relative tracking ends



Selected Results

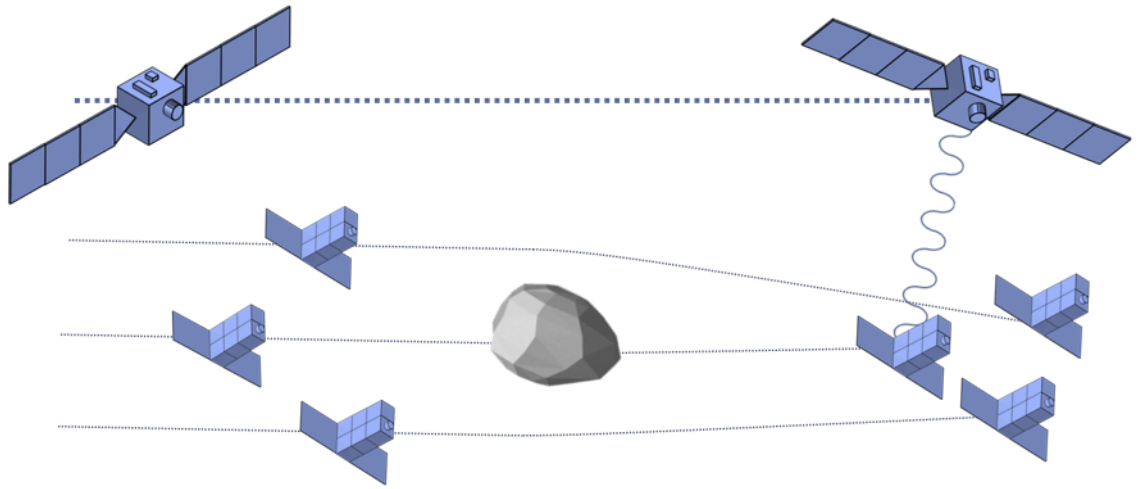
- Studied 300 m, 500 m, **800 m** diameter asteroids
- All three asteroids are measureable to < 5% mass uncertainty



Asteroid Mean Diameter (m)	True GM (km^3/s^2)	Estimated GM 1σ (%)
300	1.88	2.9
500	8.73	1.6
800	35.78	0.4

Conclusions

- The mass of 2023 PDC is easily measureable if the flyby reconnaissance mission has DopGrav
- Optimistic scenario
  - 2023 PDC is large for an expected near-term PHA
  - The flyby velocity is very slow
  - Generous assumptions of tracking schedule and noise sources
  - Targeting the test-mass close approach is still a challenge
- Next step: target smaller (140 m) asteroid with more test-masses



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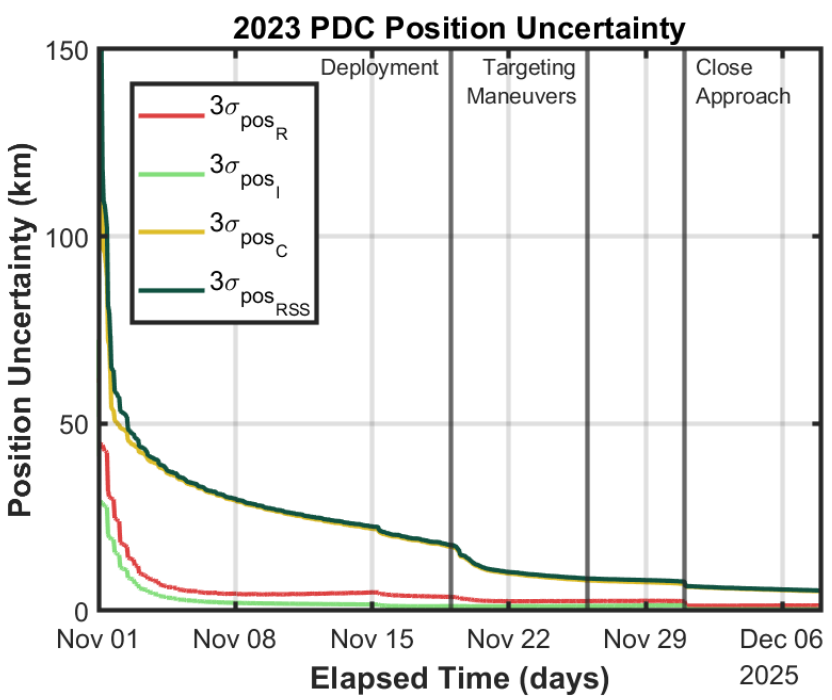
Simulation Setup

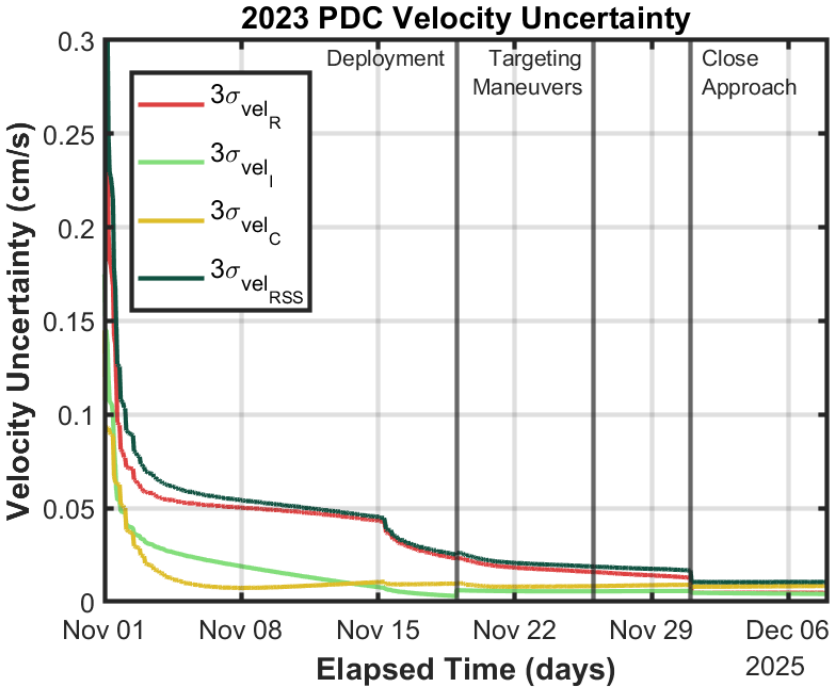
- Used Ansys Government Initiative's (AGI's) Orbit Determination Toolkit (ODTK) for simulating and processing measurements
- Covers four weeks before C/A and one week after
- Studied 300 m, 500 m, **800 m** diameter asteroid
- Estimates host's and test-mass's position, velocity, & SRP coefficients, maneuvers, updates to asteroid's ephemeris, and asteroid GM

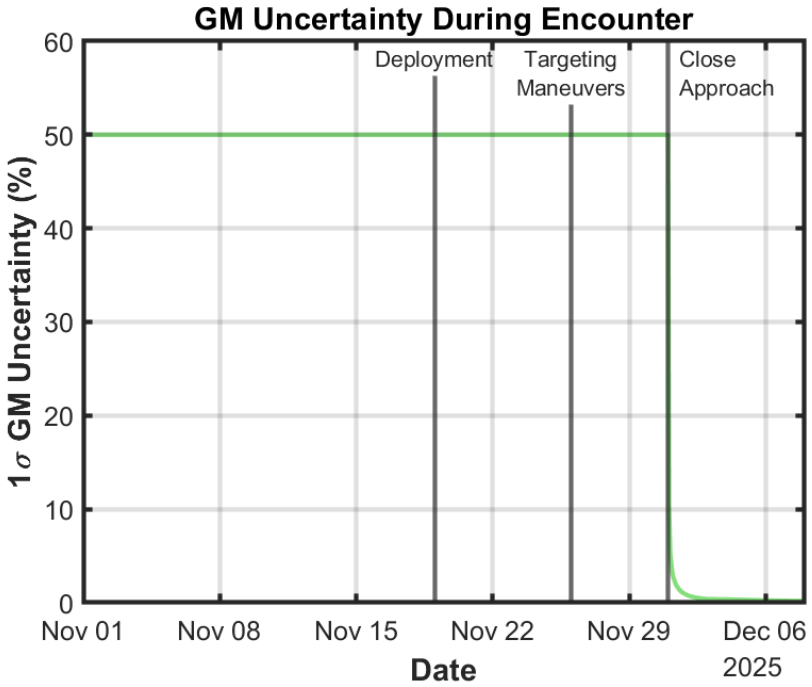
Modality	Schedule
DSN	1 meas per minute continuously to available ground station
OpNav	12 meas 3x per day 120 meas 3x per day in closest 2 days
OpGrav	3 meas every hour 30 meas every hour in closest 2 days
DopGrav	1 meas per minute continuously

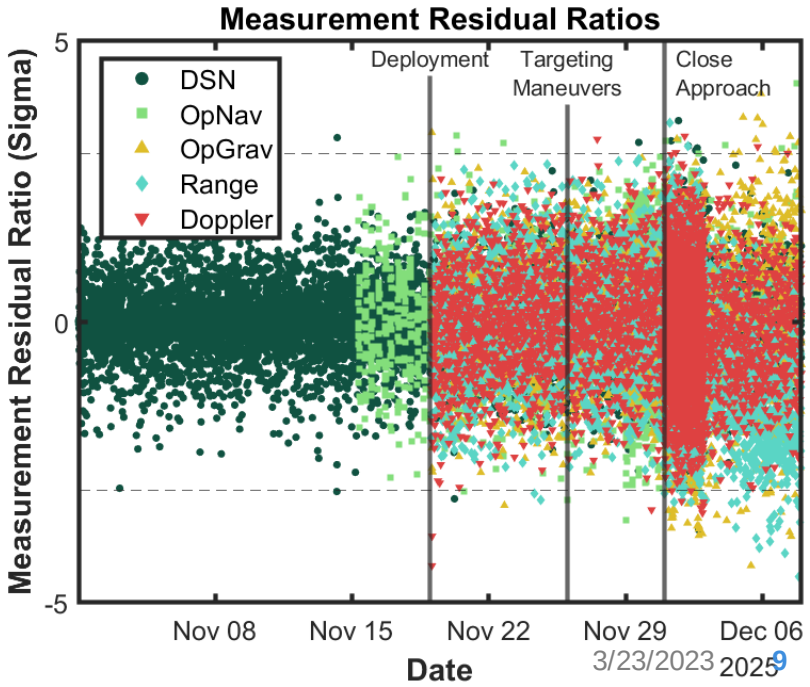
Parameter	Value
Host Spacecraft Mass	120 kg
Host Spacecraft Area	5 m^2
Host Spacecraft C_R	1
Test-mass Mass	12 kg
Test-mass Area	1 m^2
Test-mass C_R	1
Host Spacecraft Flyby Radius	50 km
Test-mass Flyby Radius	0.5 km

800 m Asteroid

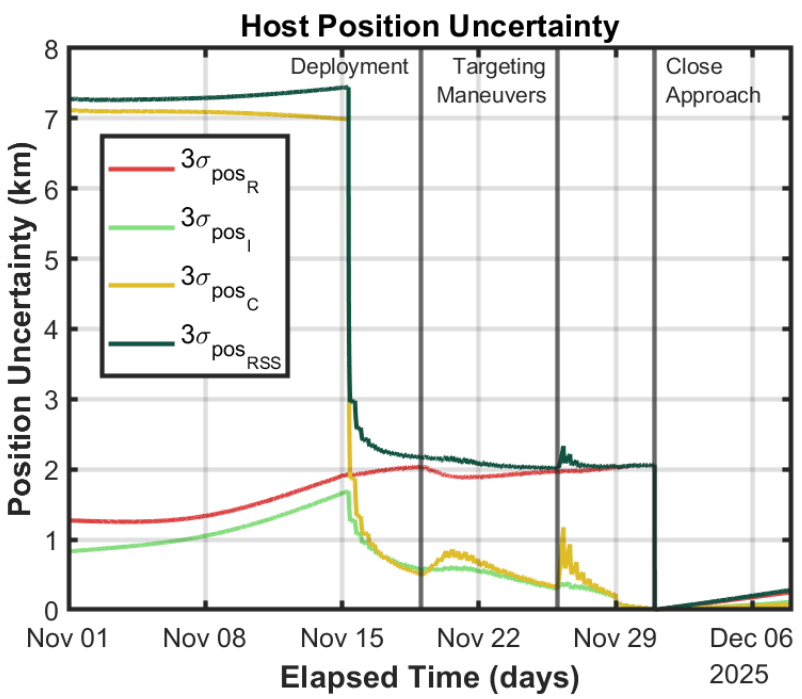


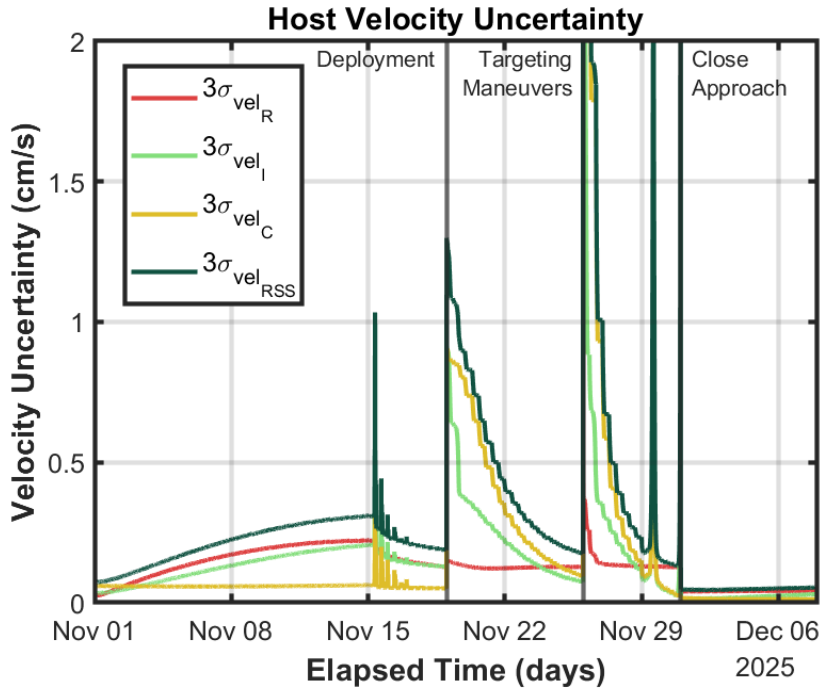


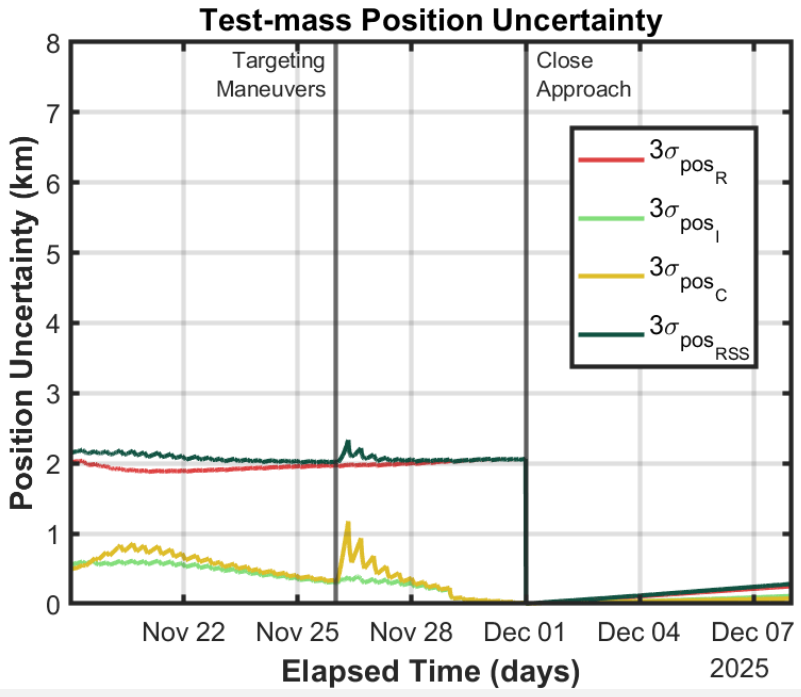


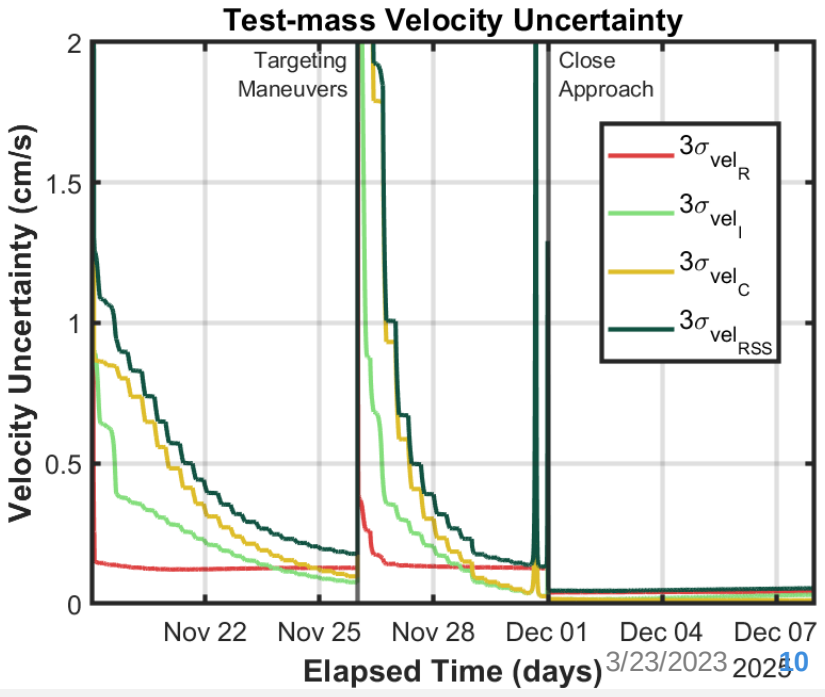


800 m Asteroid

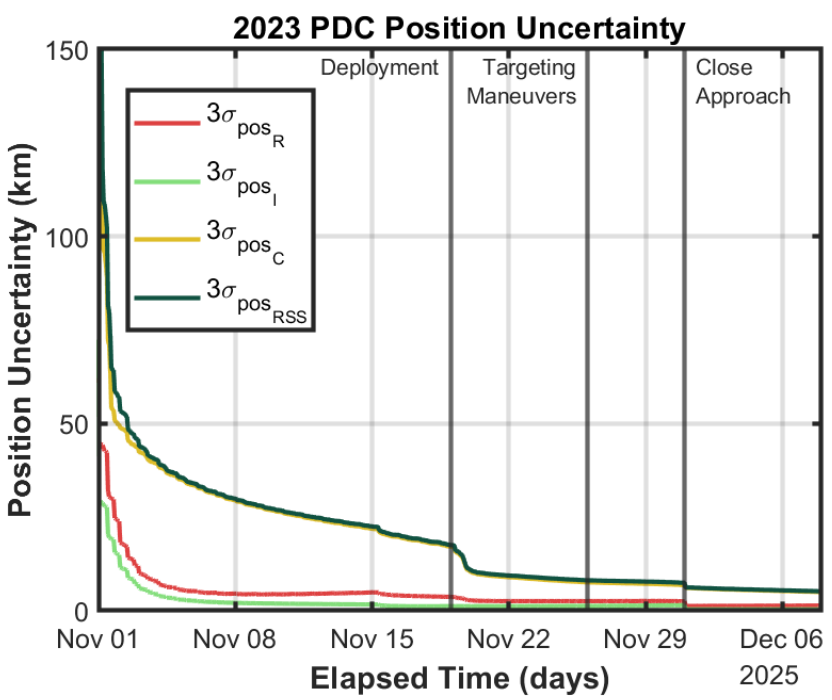


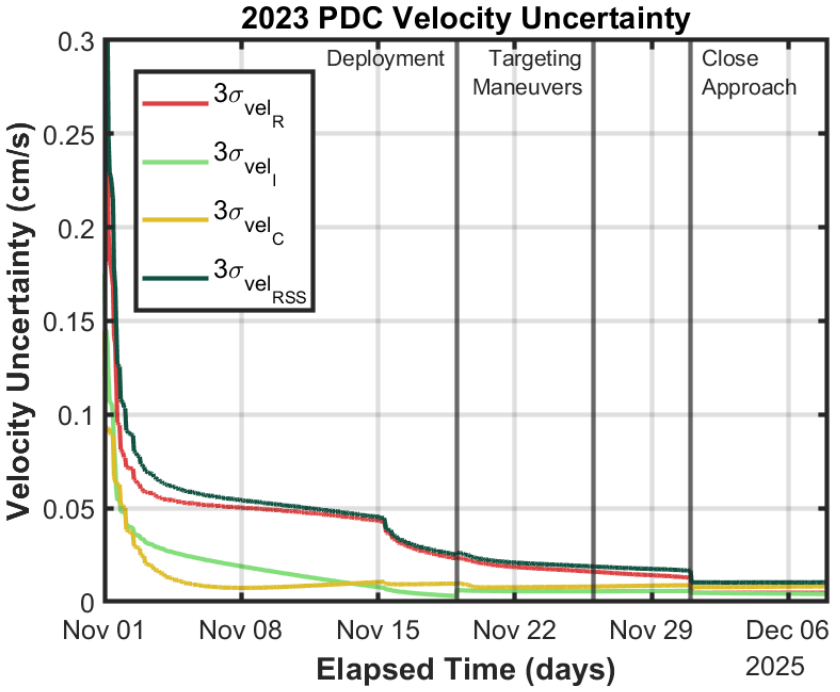


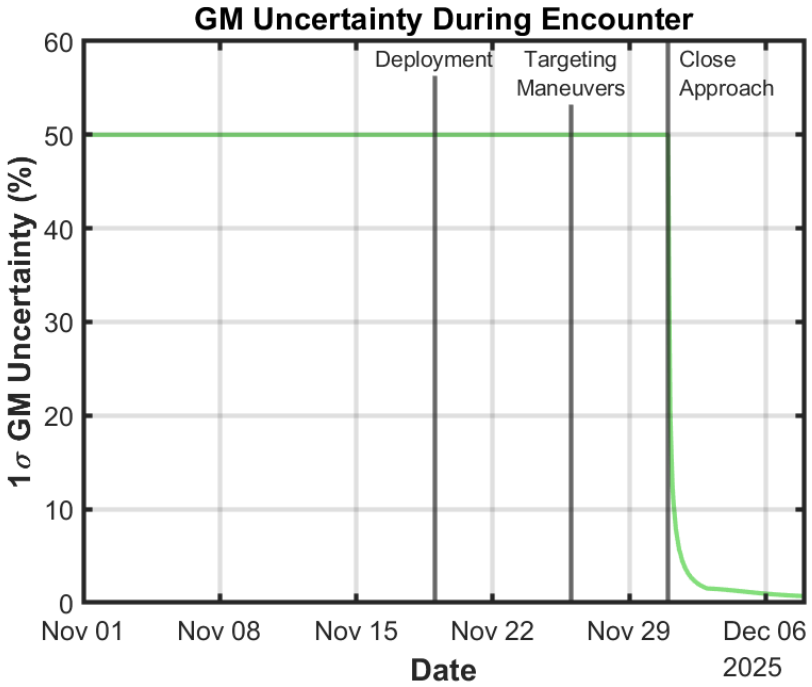


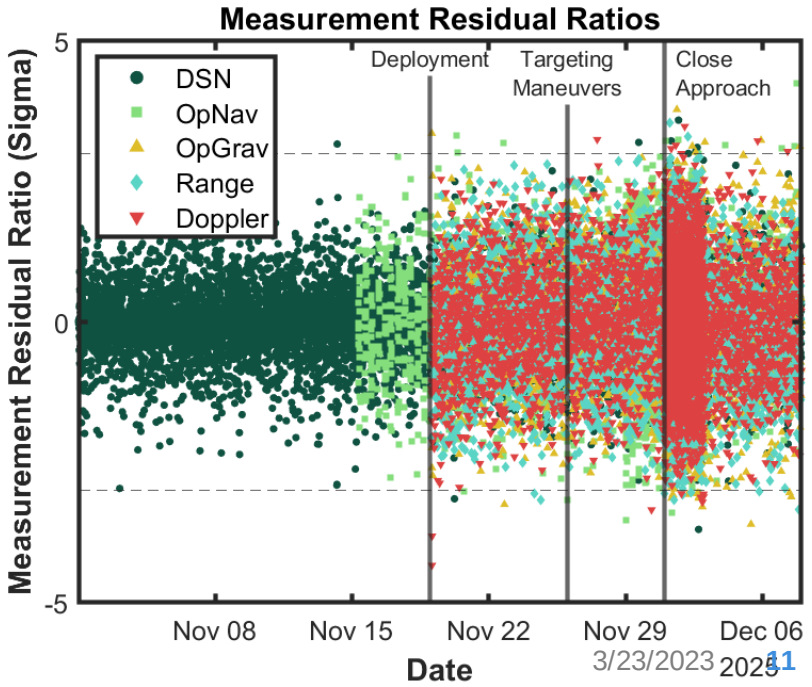


500 m Asteroid









500 m Asteroid