Lofted Regolith Sampling of Small Bodies

Jay W. McMahon
Brad Cheetham
Space Resources Roundtable
Colorado School of Mines
June 8, 2016

How do we prospect on small bodies?

Microgravity …

Structural Uncertainties …

No rivers…

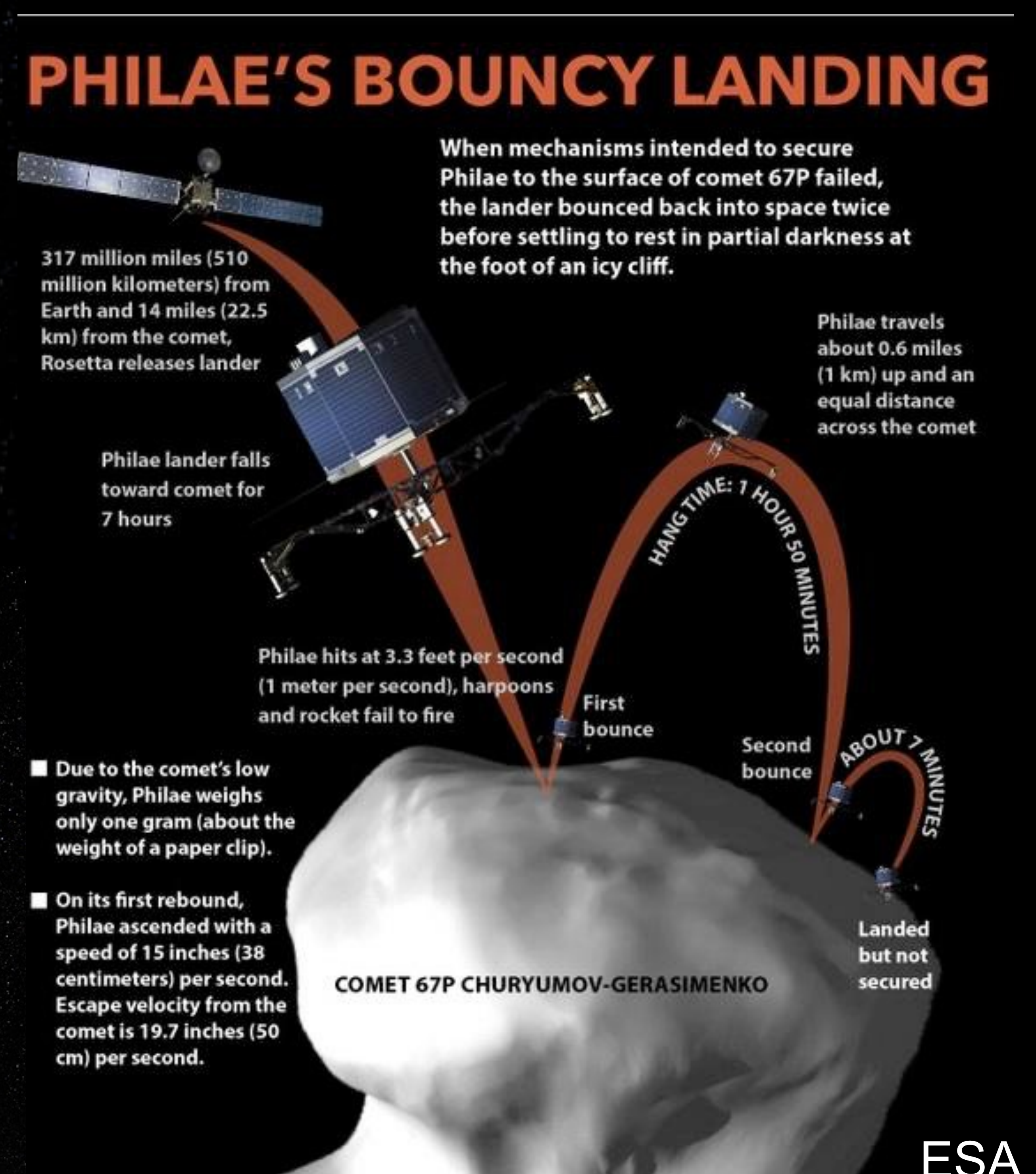
LoRS provides an architecture which is robust to these issues

Current Small Body Sampling/Prospecting

OSIRIS-REx
ASTEROID SAMPLE RETURN MISSION

www.asteroidmission.org

http://astro.oamaru.net.nz/2015/12/japanese-hayabusa-2-asteroid-spacecraft.html



ESA

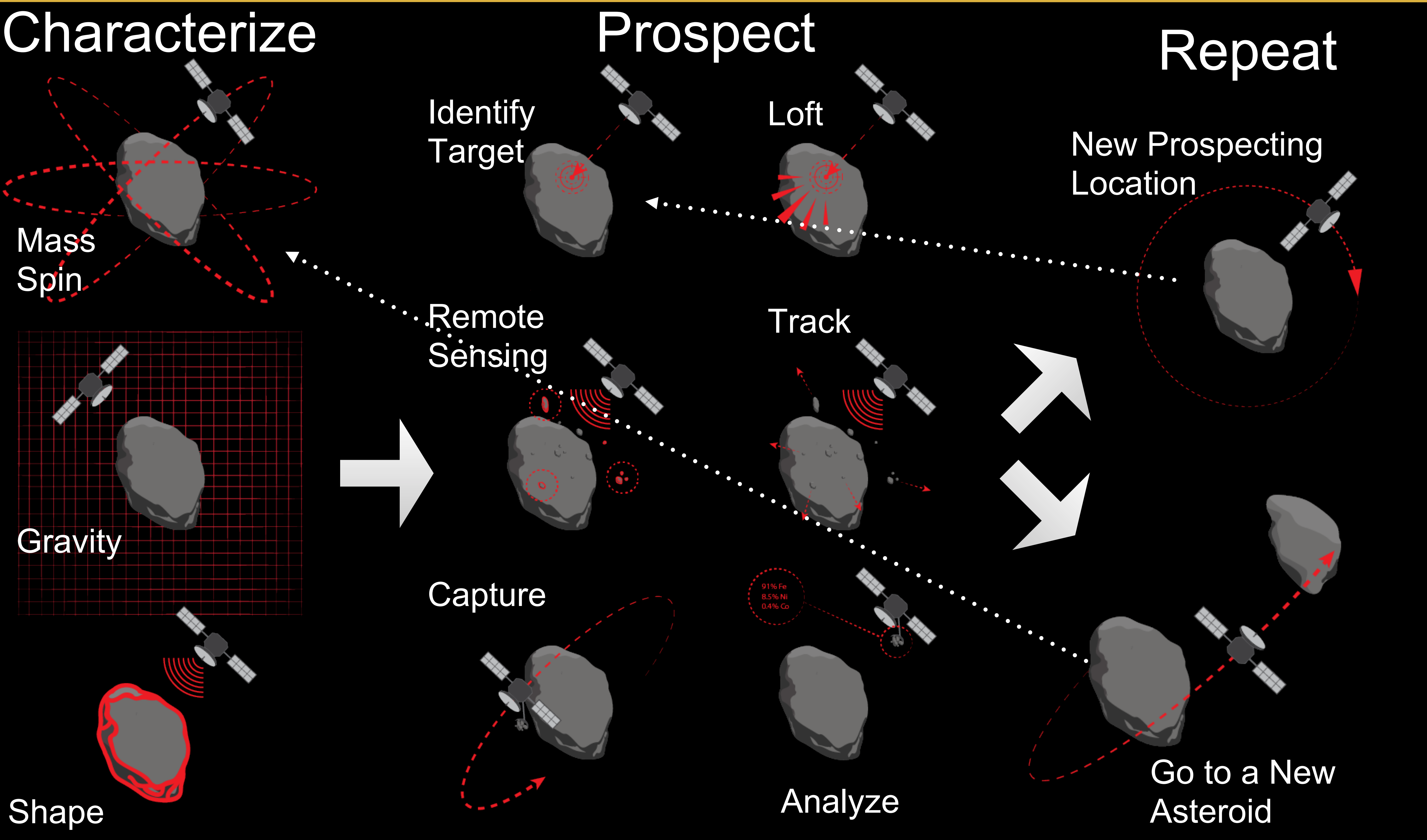
Lofted Regolith Sampling (LoRS)

- A safe, “cheap,” repeatable way to prospect small bodies
- Concept enabled by low gravity and large relative effect of solar radiation pressure
- Lofting debris
  - is energetically easy
  - is size sorted by SRP
  - dust quickly goes away
  - reveals unweathered material
- Relative speeds are very slow - safe
- No spacecraft hardware needs to be put on the asteroid to start, thus not risking loss of mission for each sample
- NASA STTR Phase I
  - Regolith Resource Robotic (T4.02) supported by KSC

Goal:

Create a robust method for obtaining material from small bodies with near-term technology

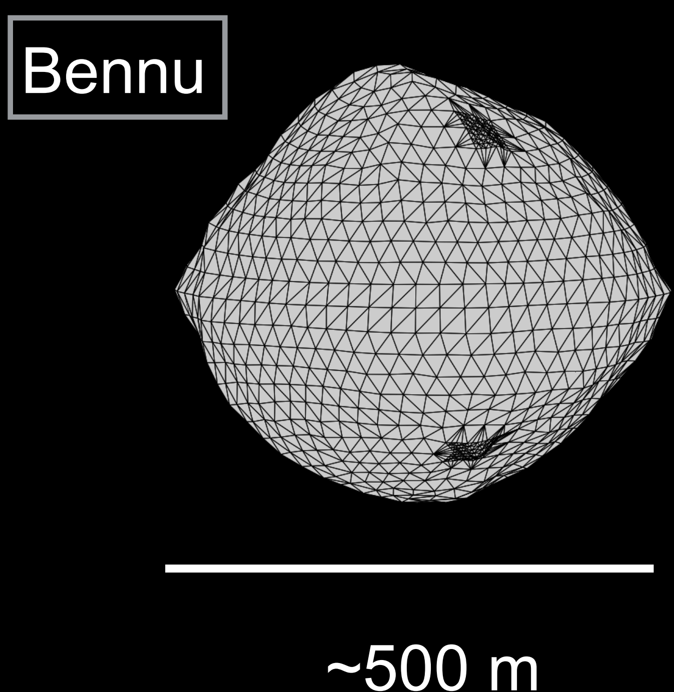
LoRS Concept of Operations

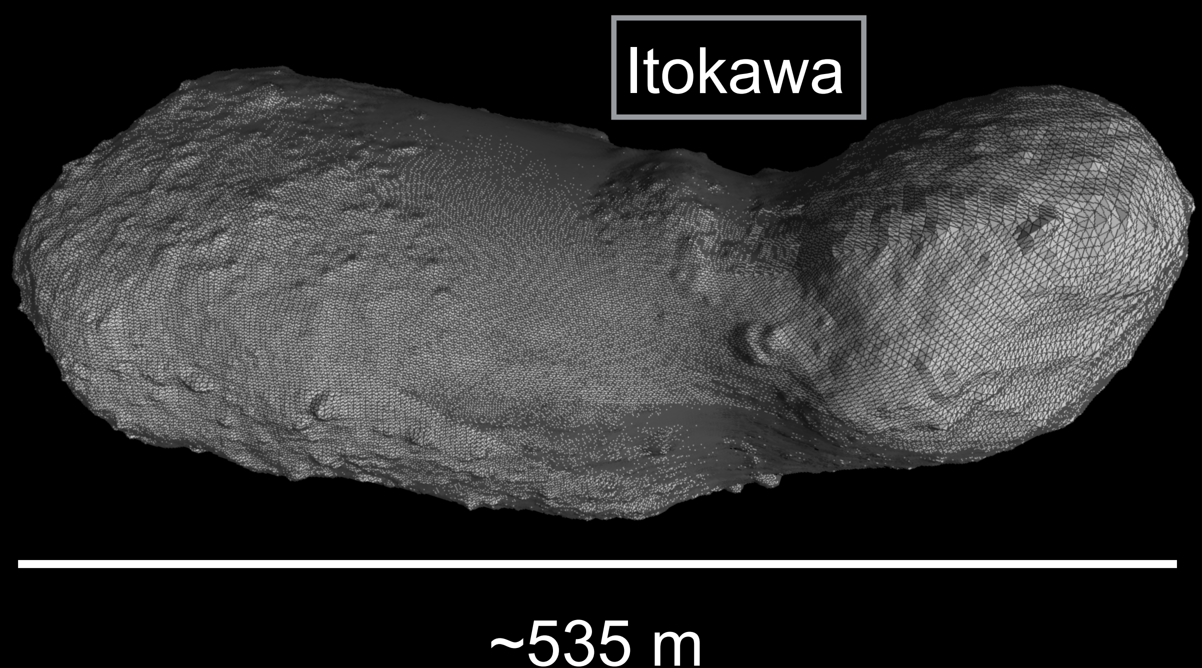


Orbital Speeds around NEAs are *slow*

Asteroid	Escape Speed [cm/s]	Circular Orbit Speed [cm/s]	Turnaround DV [cm/s]	Plane Change DV [cm/s]
Bennu	20.3	5.1	3.1	0.40
Itokawa	13.0	3.4	1.4	0.19
Ryugu r ~435 m	36.5	12.0	5.8	0.67

(@ 2 km) (@ 50 km) (50x2 km)



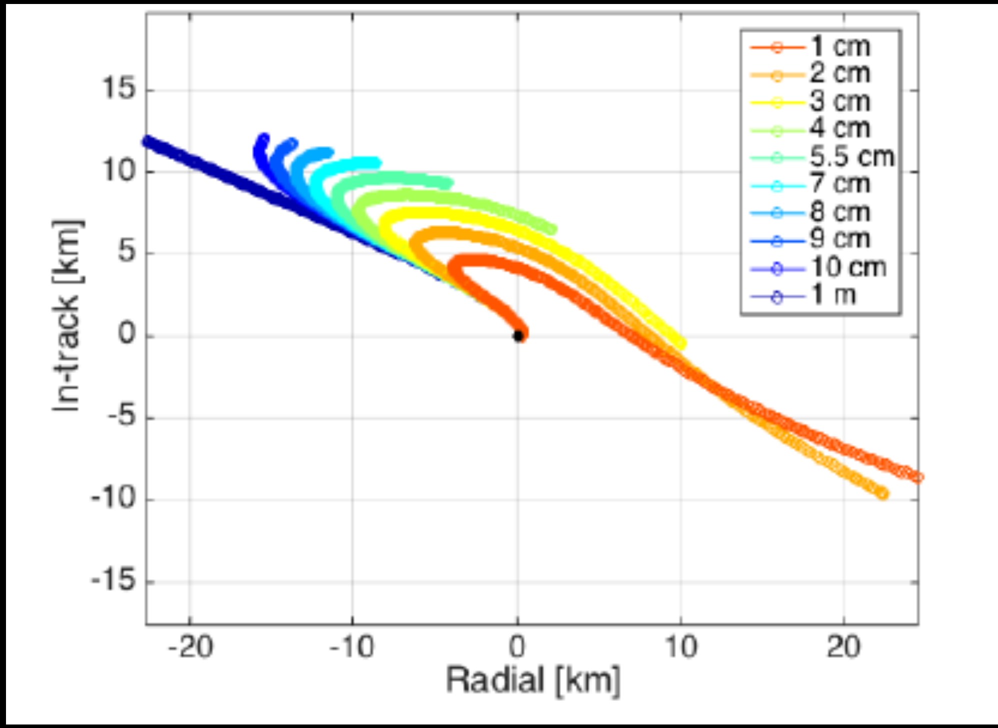


Debris Propagation

- What happens to material lofted from a small body?
  - it generally escapes or re-impacts
- To show this, we explored the parameter space with over 80,000 trajectories
  - note that trajectories are symmetric in z-direction, so have effectively run 270° azimuth as well
- Bennu sized asteroid at 1AU

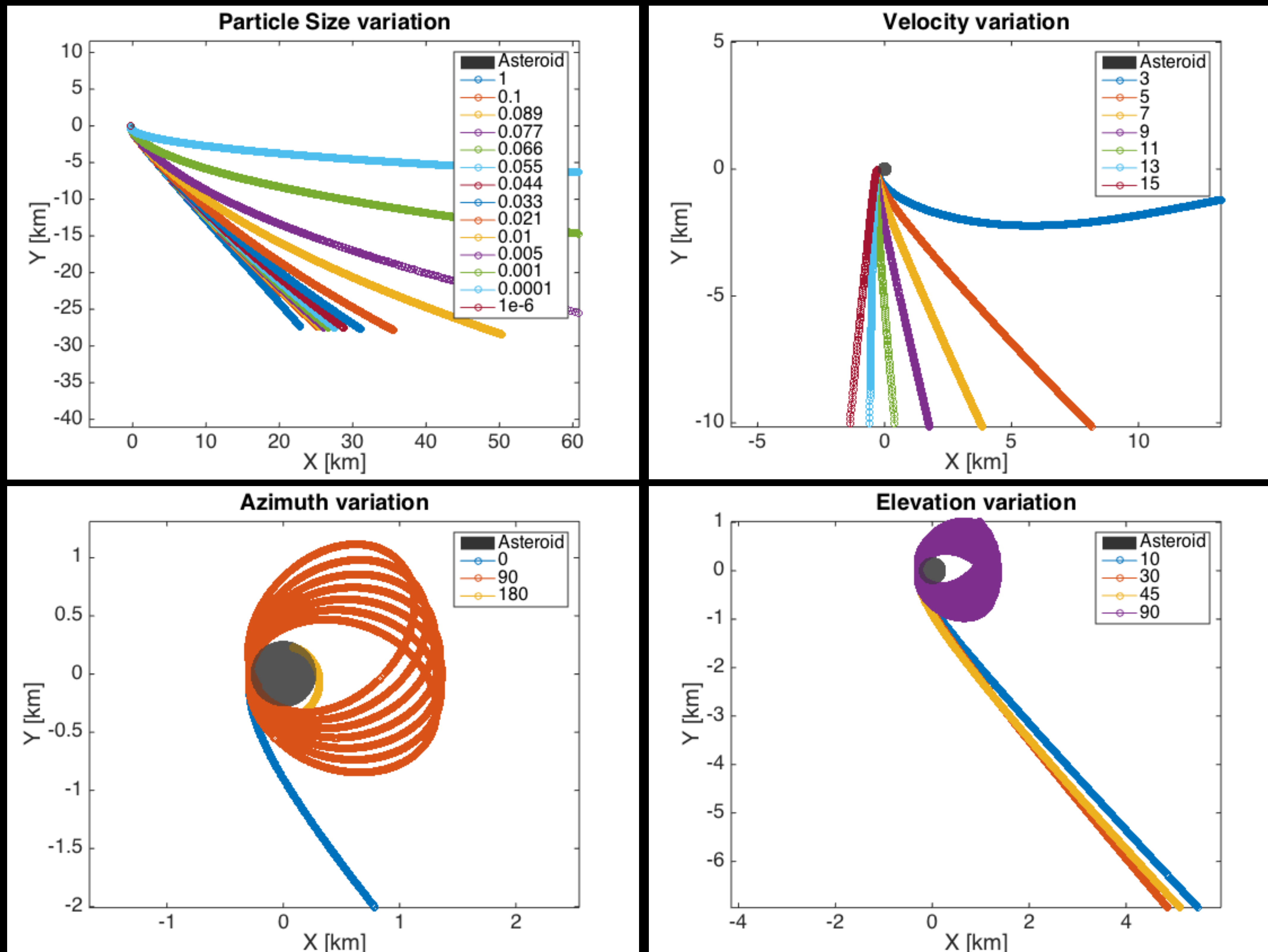
Table 1: Parameter space for lofted regolith trajectories

Parameter	Values Tested
Particle Radius	[100, 10, 8.9, 7.8, 6.6, 5.5, 4.4, 3.3, 2.1, 1] cm
Latitude	[80, ±64, ±48, ±32, ±16, 0] deg
Longitude	[0, 36, 72, 108, 144, 180, 216, 252, 288, 324] deg
Launch Azimuth	[0, 90, 180] deg
Launch Elevation	[10, 30, 45, 90] deg
Launch Velocity	[3, 5, 7, 9, 11, 13, 15] cm/s



Debris Propagation

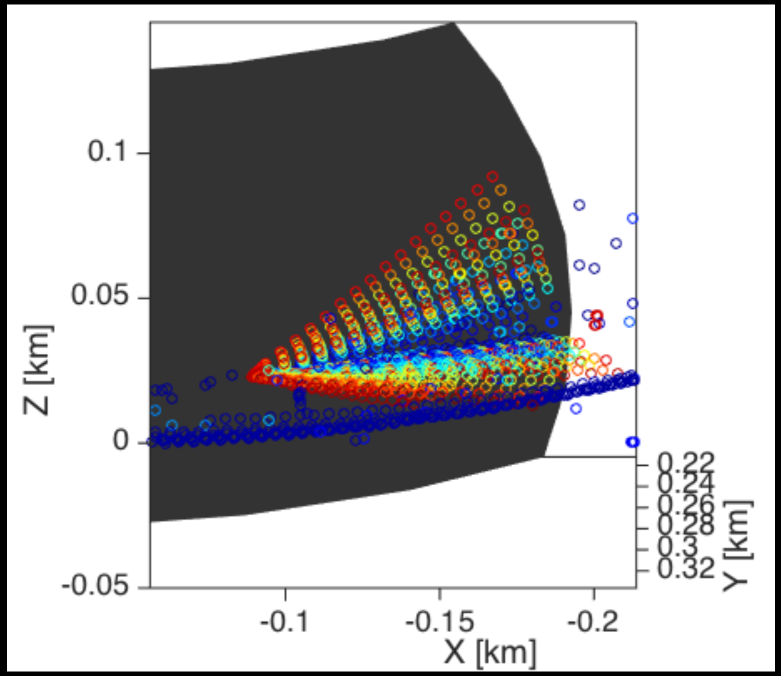
SRP

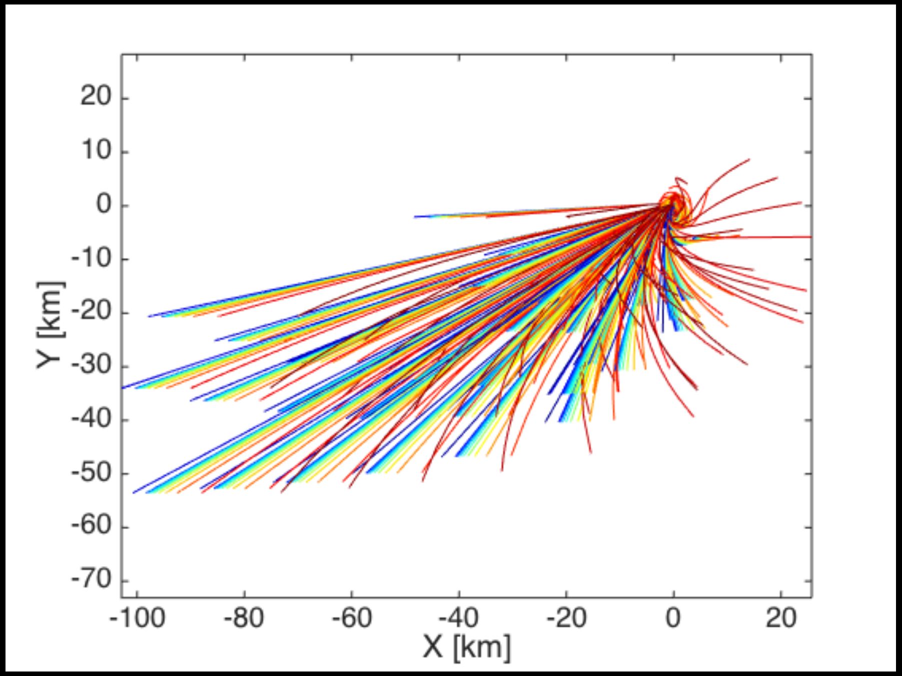


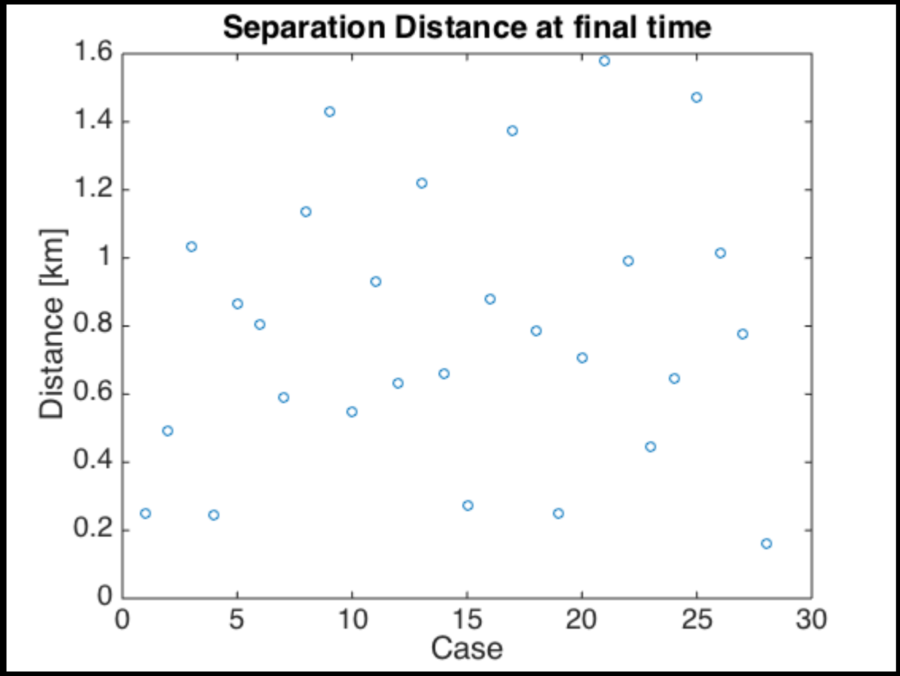
Debris Propagation

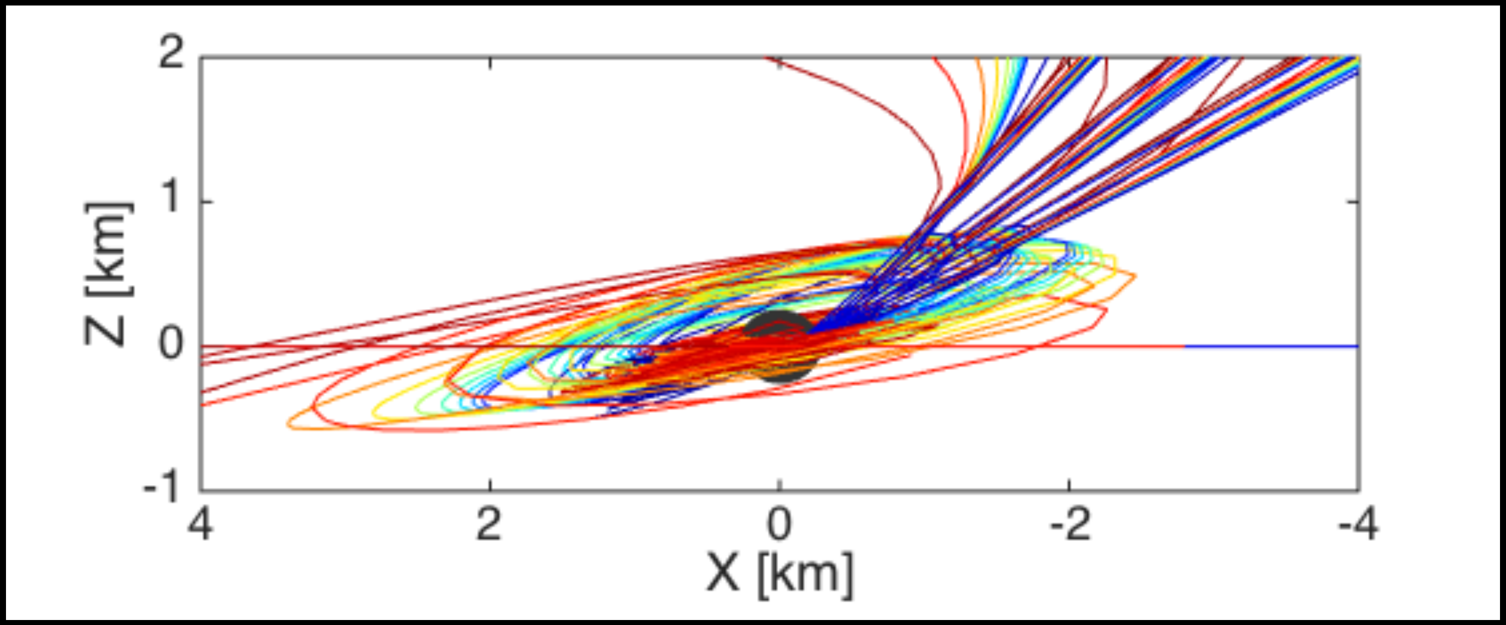
- 5 days
- 1 site, 108 longitude, 0 latitude

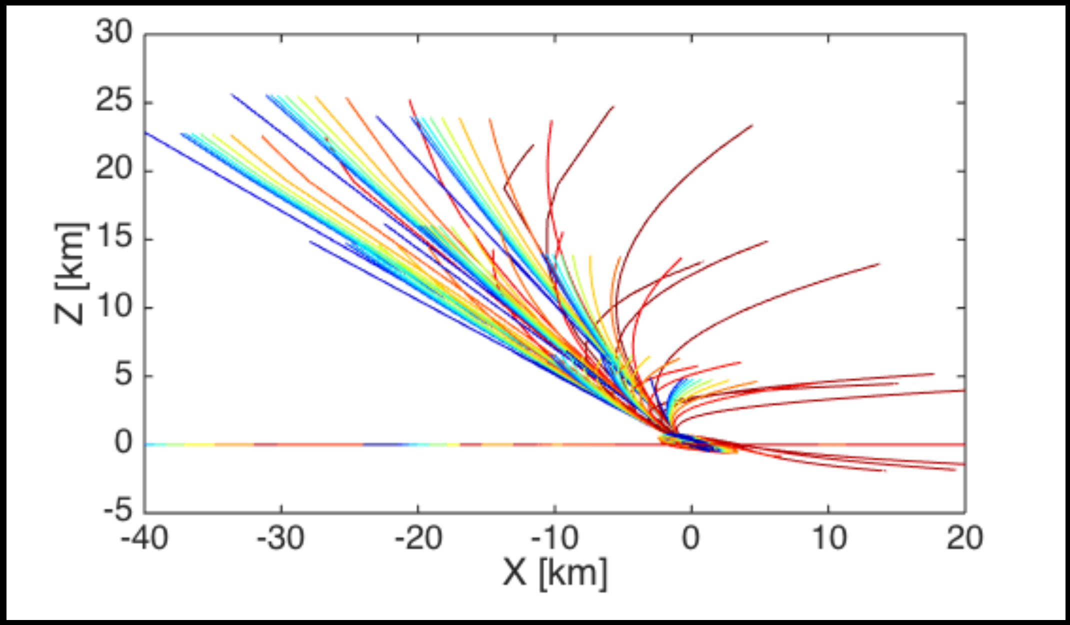
- SRP sorts material by size
- Although some trajectories appear close, they are separated when looking at time





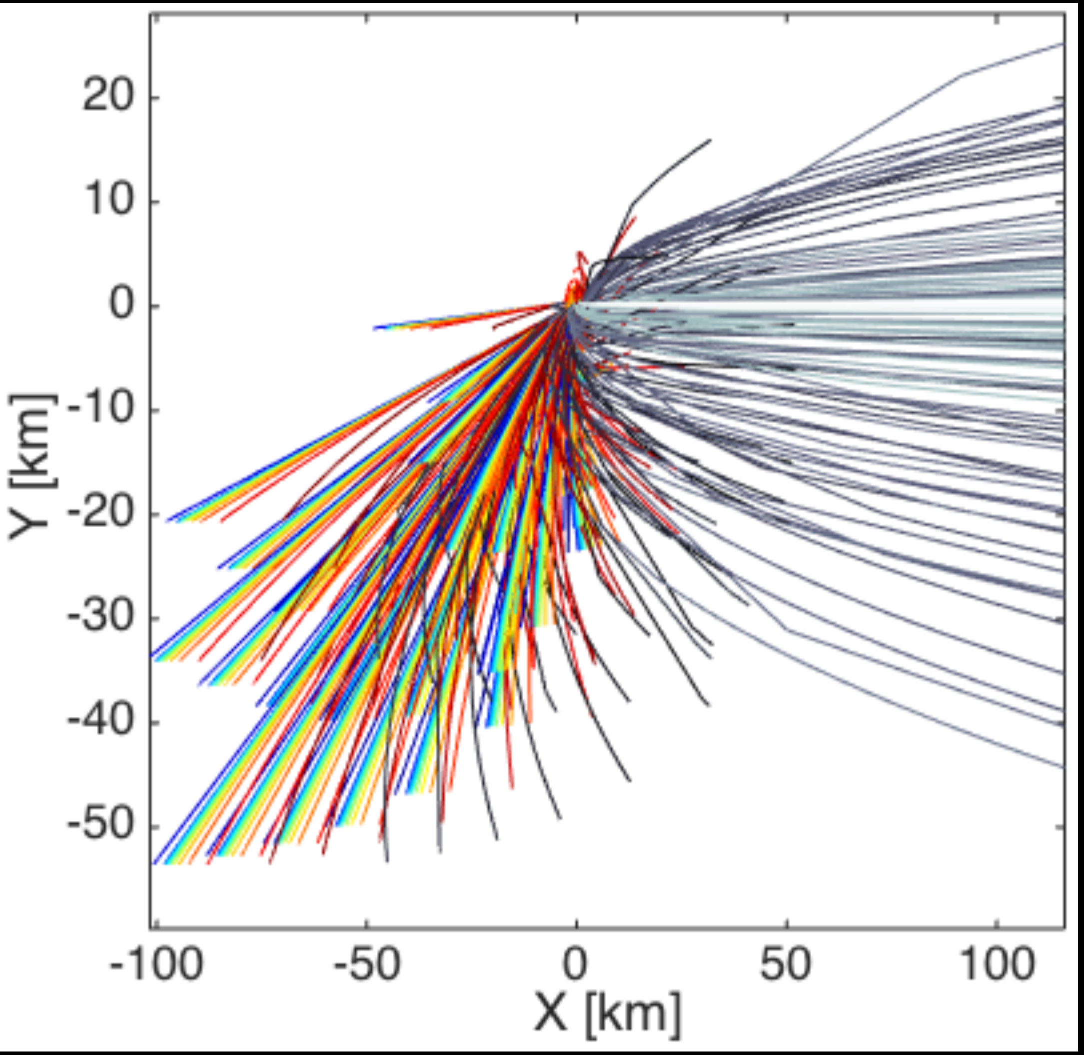






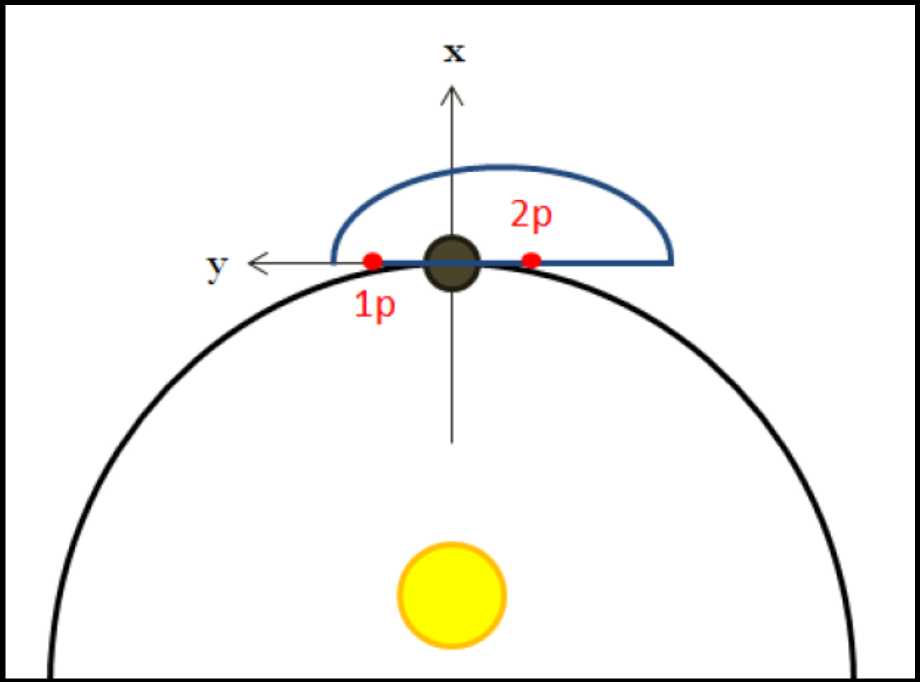
Dust Mitigation

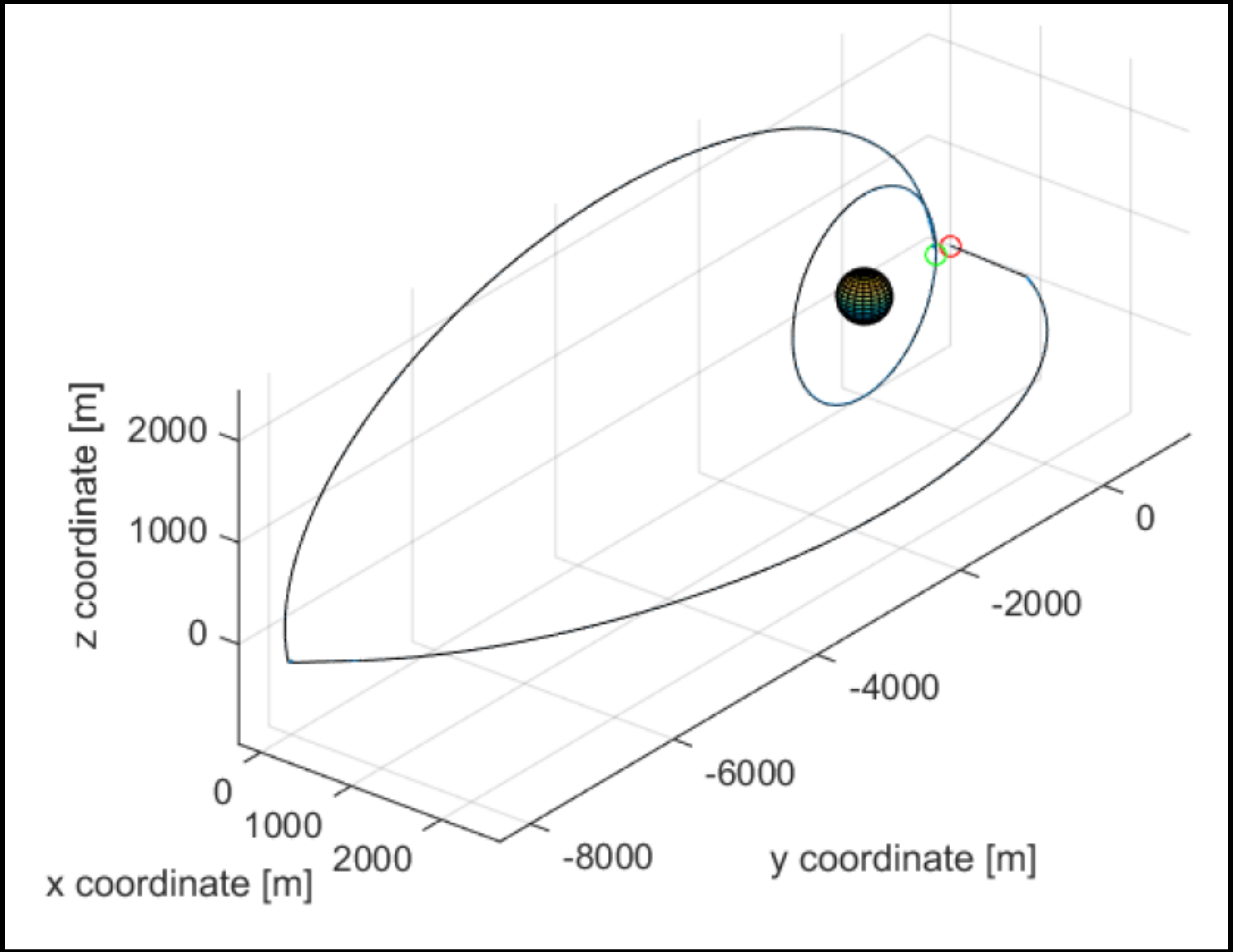
- What about all the dust?
  - –it goes away - FAST
- Looked at 1 μm - 5 mm dust
  - –33,000 more trajectories
- In all cases, the dust either immediately re-impacts, or reaches 100s of km in days
  - –the plot is cut off at the right, dust reaches this disance in ~1 day
- Not worried about significant residual dust



Making maneuverability *cheap*

- 7 cm/s to raise apoapse to 8km
- 3 cm/s to change inclination 90 degrees!
- ~6.5g of fuel with Dawn's ion engine and a 2000 kg s/c

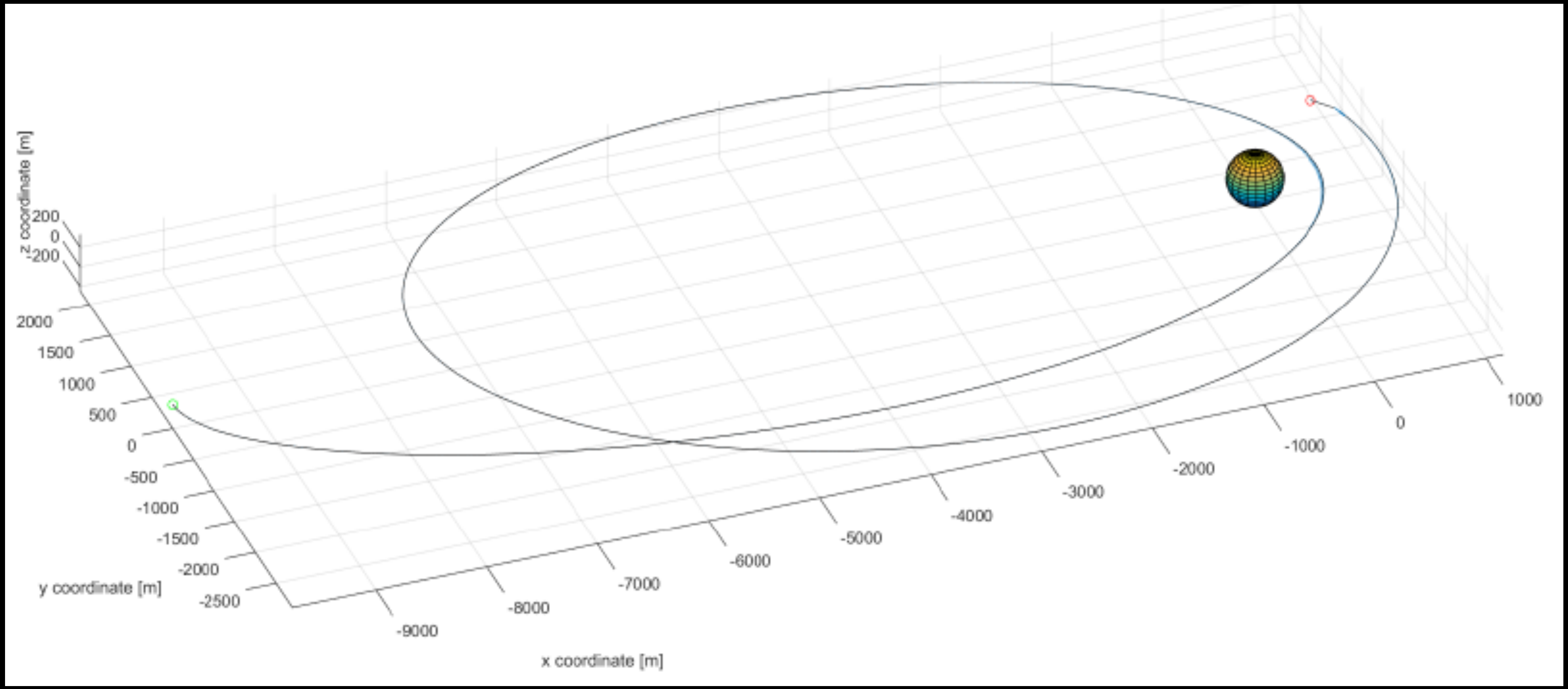


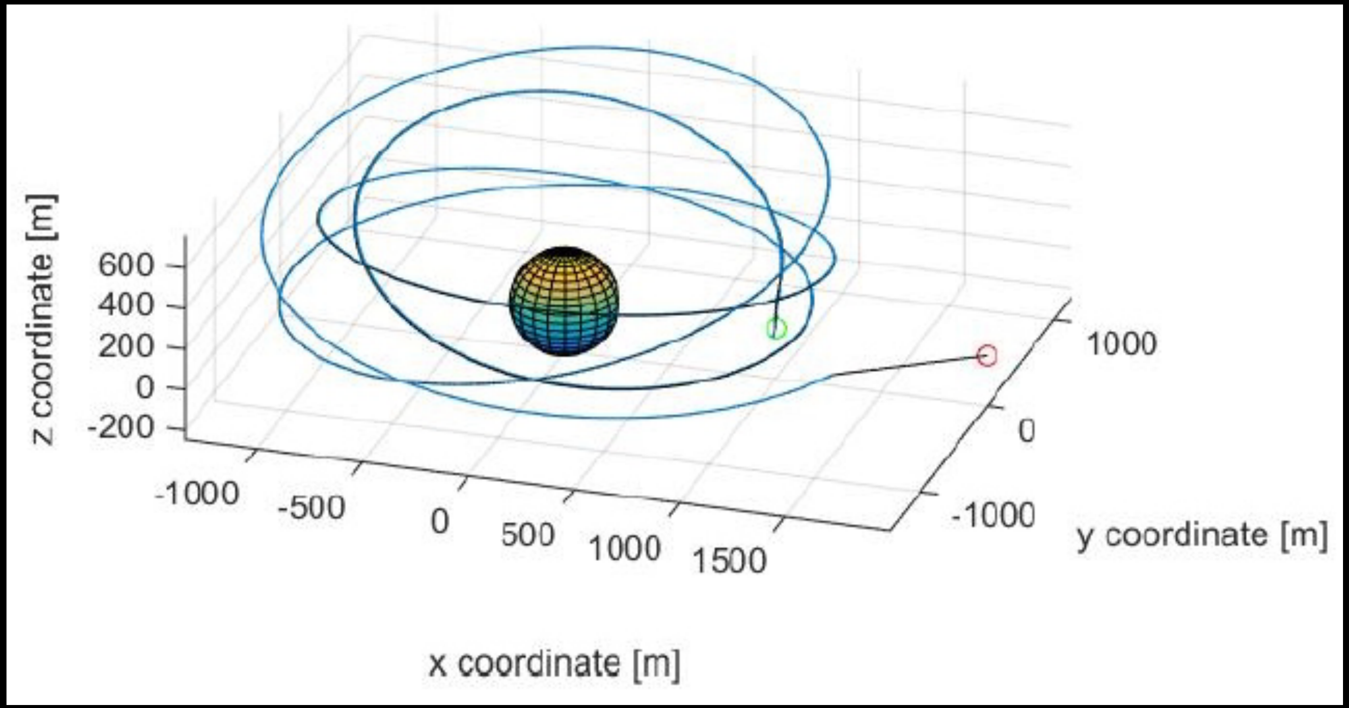


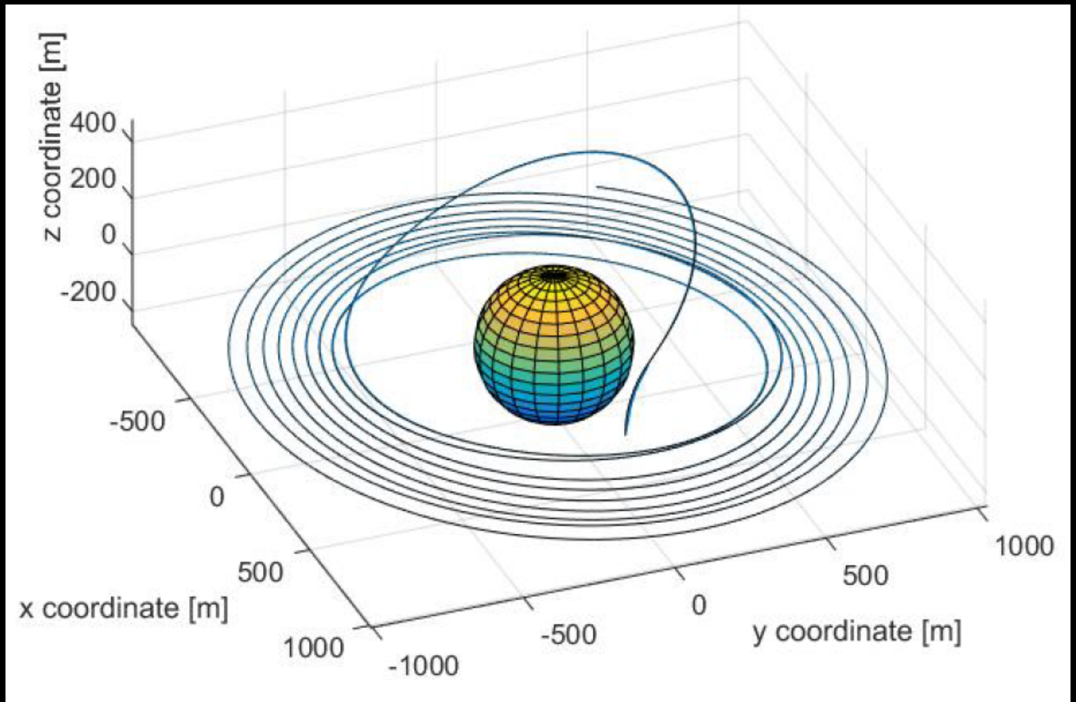
Spacecraft's propulsion characteristics used in the simulation

Parameter	**Symbol**	**Value**
Maximum thrust force	T_{max}	0.090 [N]
Specific impulse	I_{sp}	3100 [s]

Other fun, and feasible, trajectories

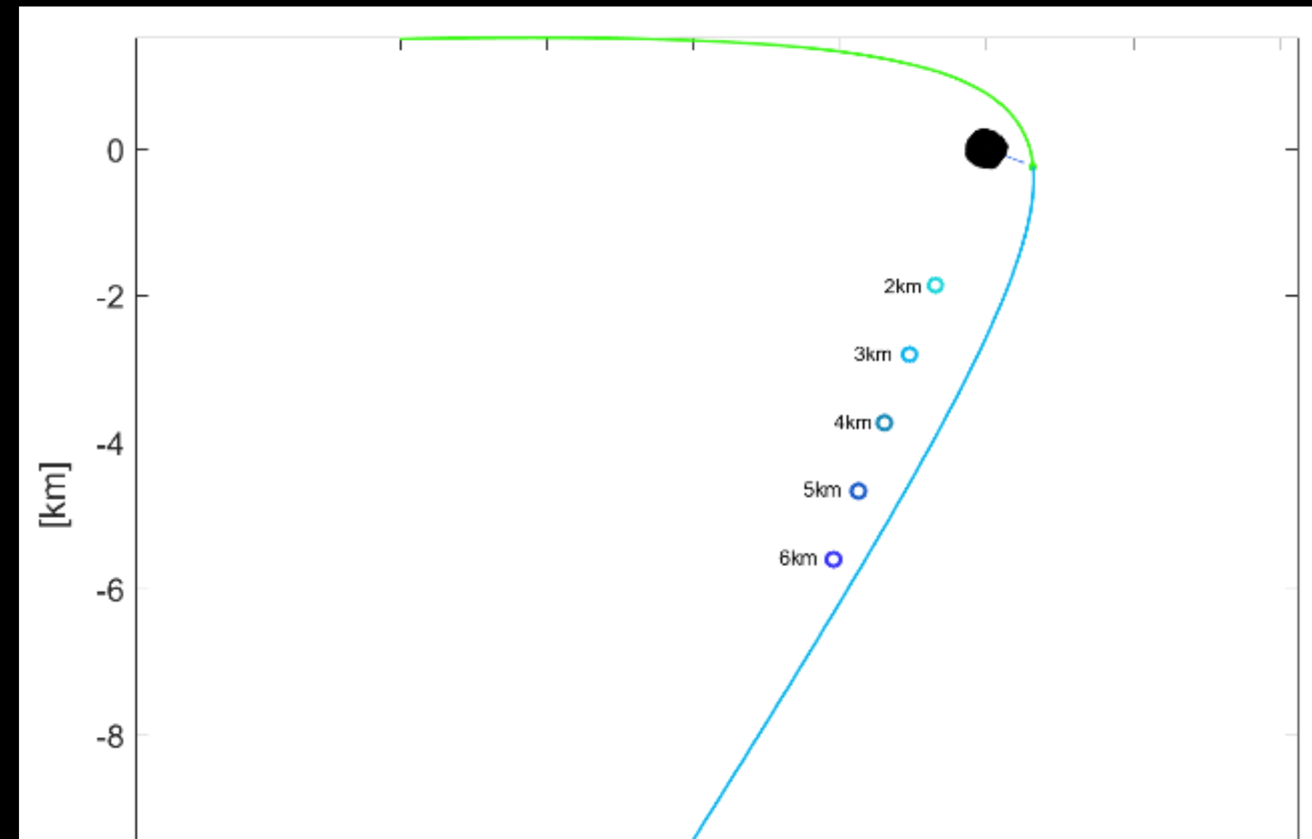


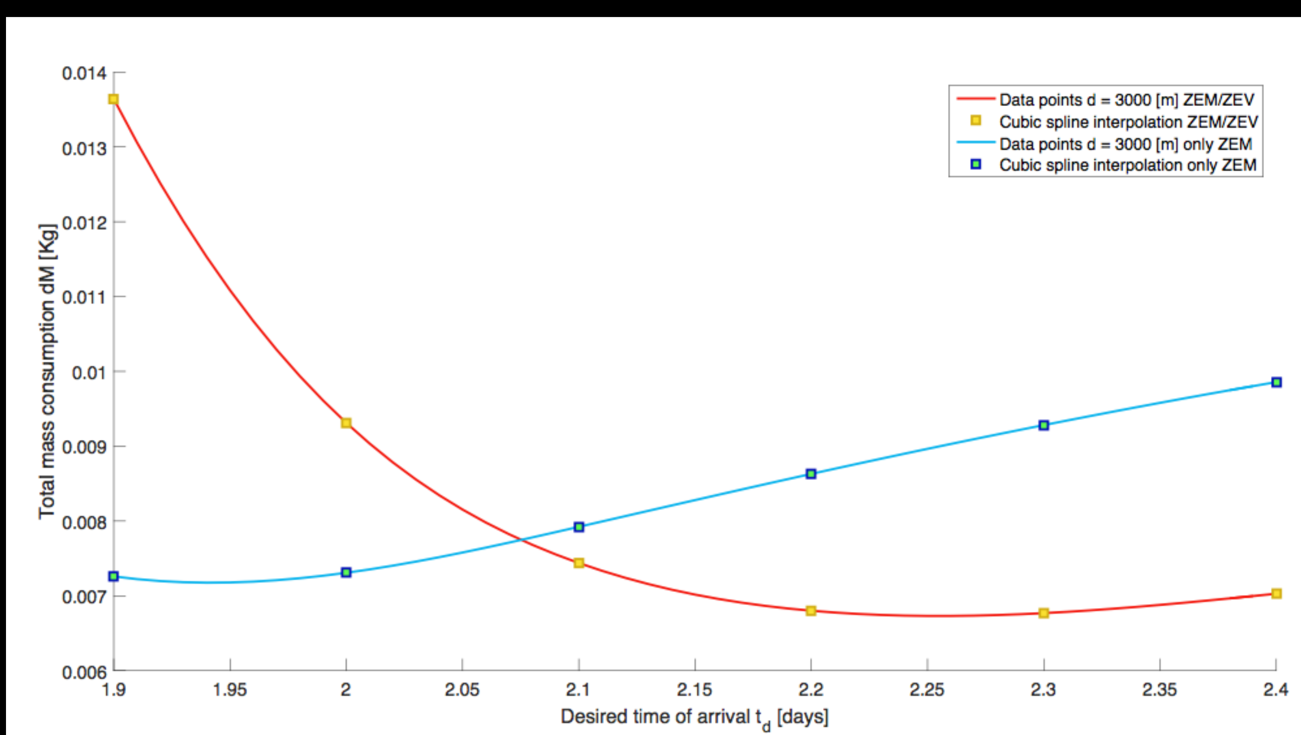


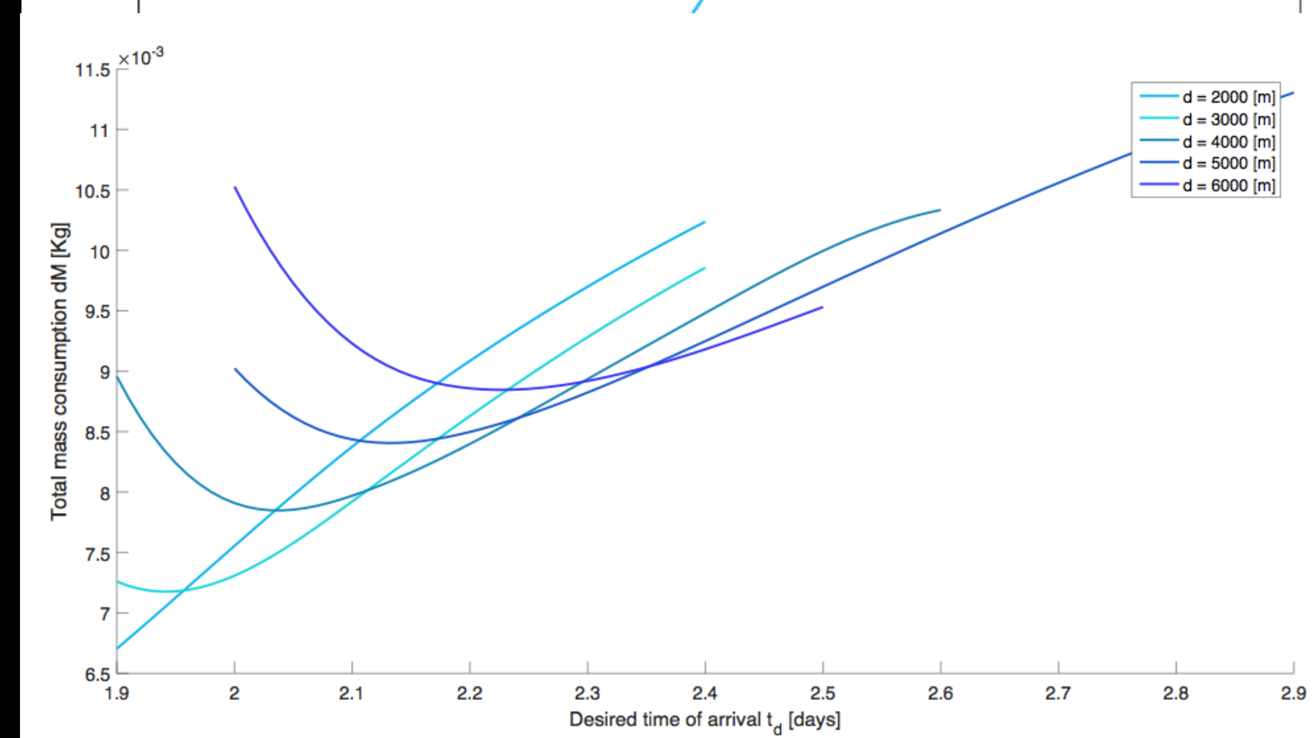


Terminal Intercept Guidance

- Implemented ZEM/ZEV guidance algorithm
- Investigated a wide variety of conditions
- Minimal fuel required
  - on the order of grams
- No optimization of trajectories
  - almost the opposite

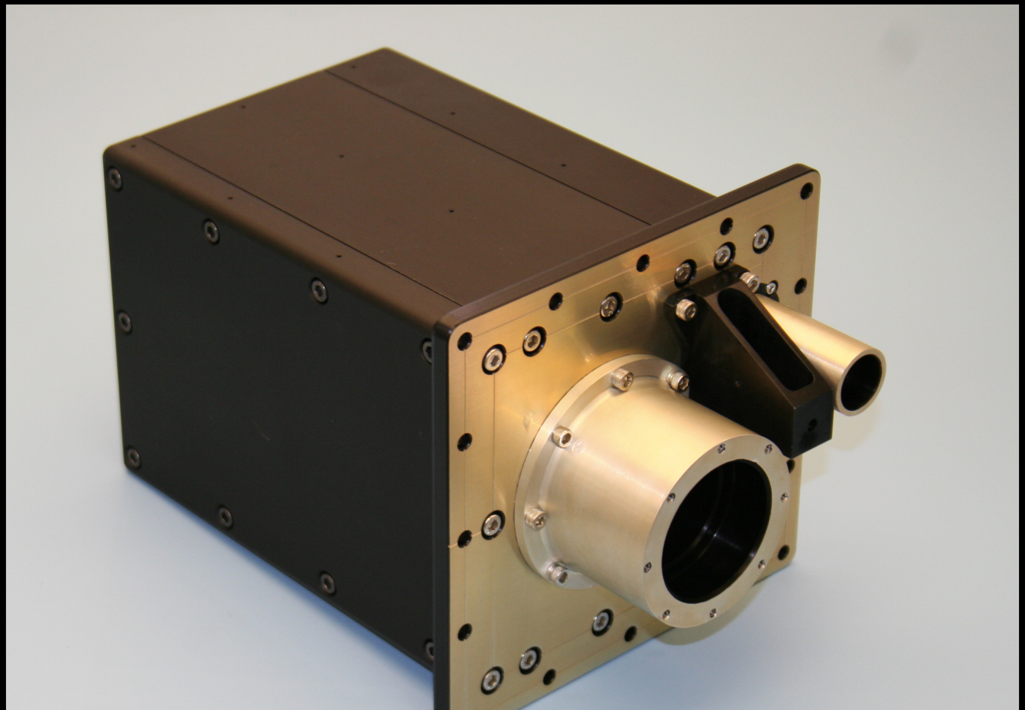




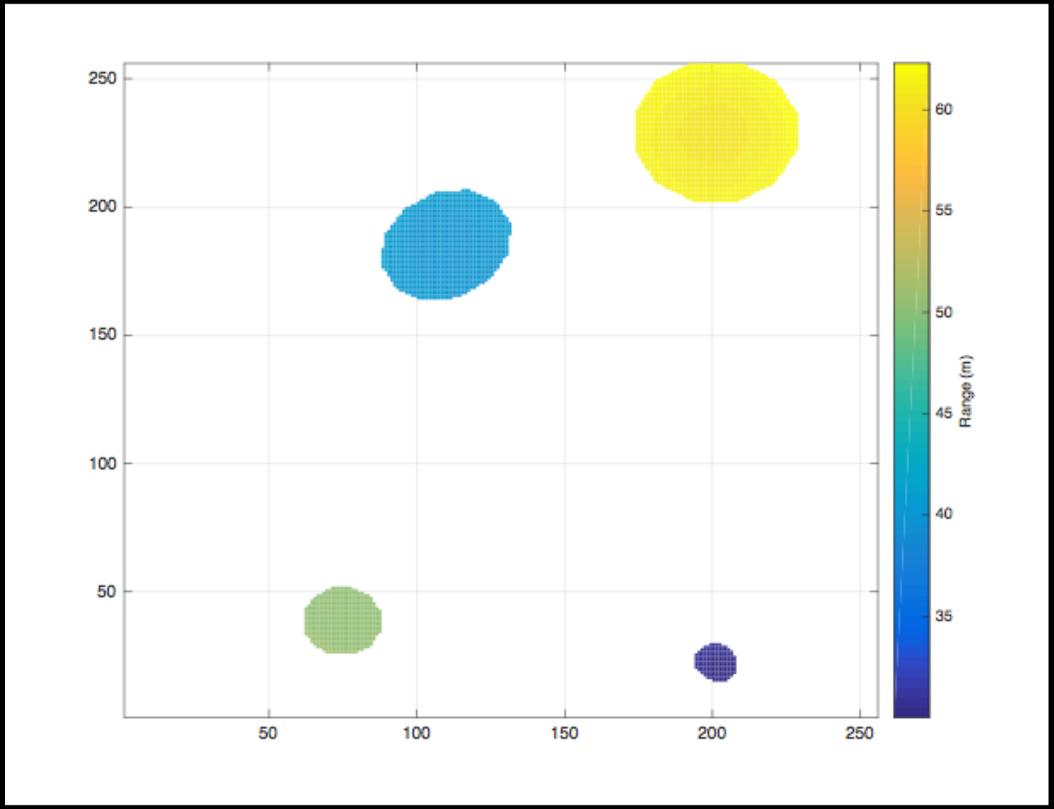


Flash LIDAR Relative Navigation

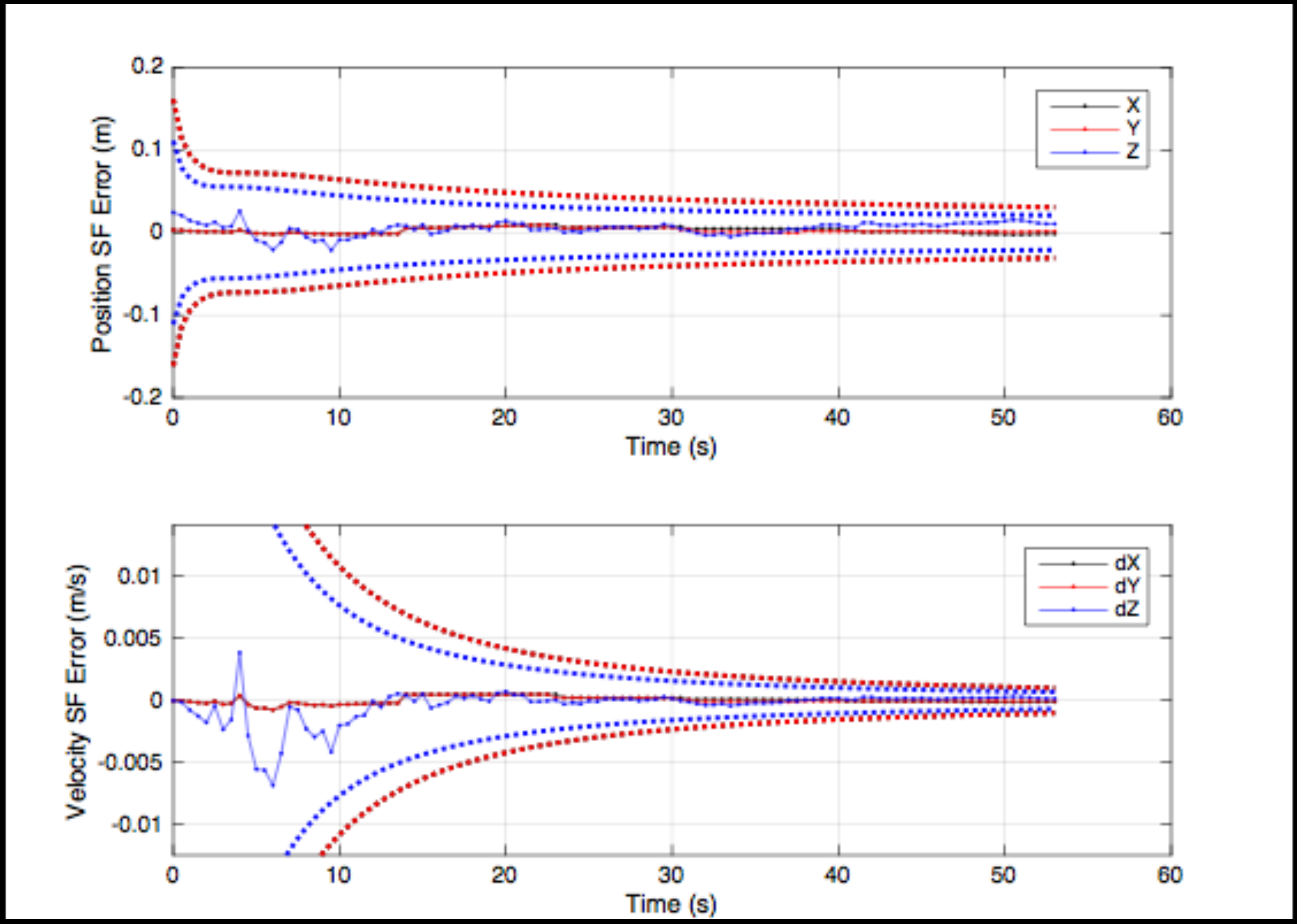
- Flash LIDAR
  - Holds great promise for improved navigation and guidance near non-cooperative RSOs
  - Combines information typically received from separate optical and single beam LIDAR instruments
  - Allows for more accurate proximity operations than optical observations
- Improved autonomy applications
  - Can navigate without intensive image processing, which allows for on-board processing
  - Targets can be quickly acquired once seen
- Flash LIDAR being flown on OSIRIS-REx
- Previously flown on the Space Shuttle to ISS as part of the STORRM package

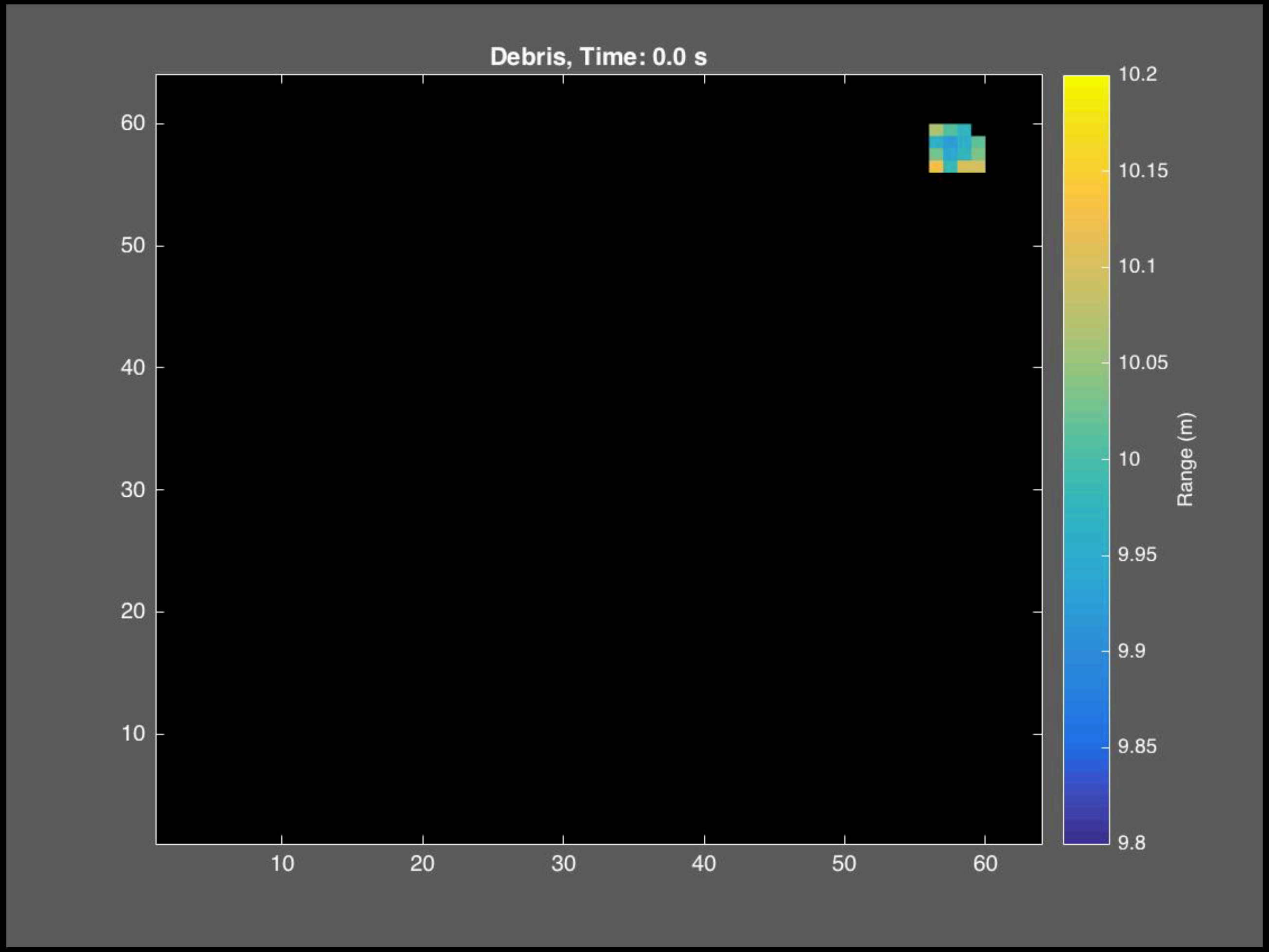


GoldenEye in the OSIRIS-REx Configuration



Flash LIDAR Relative Navigation



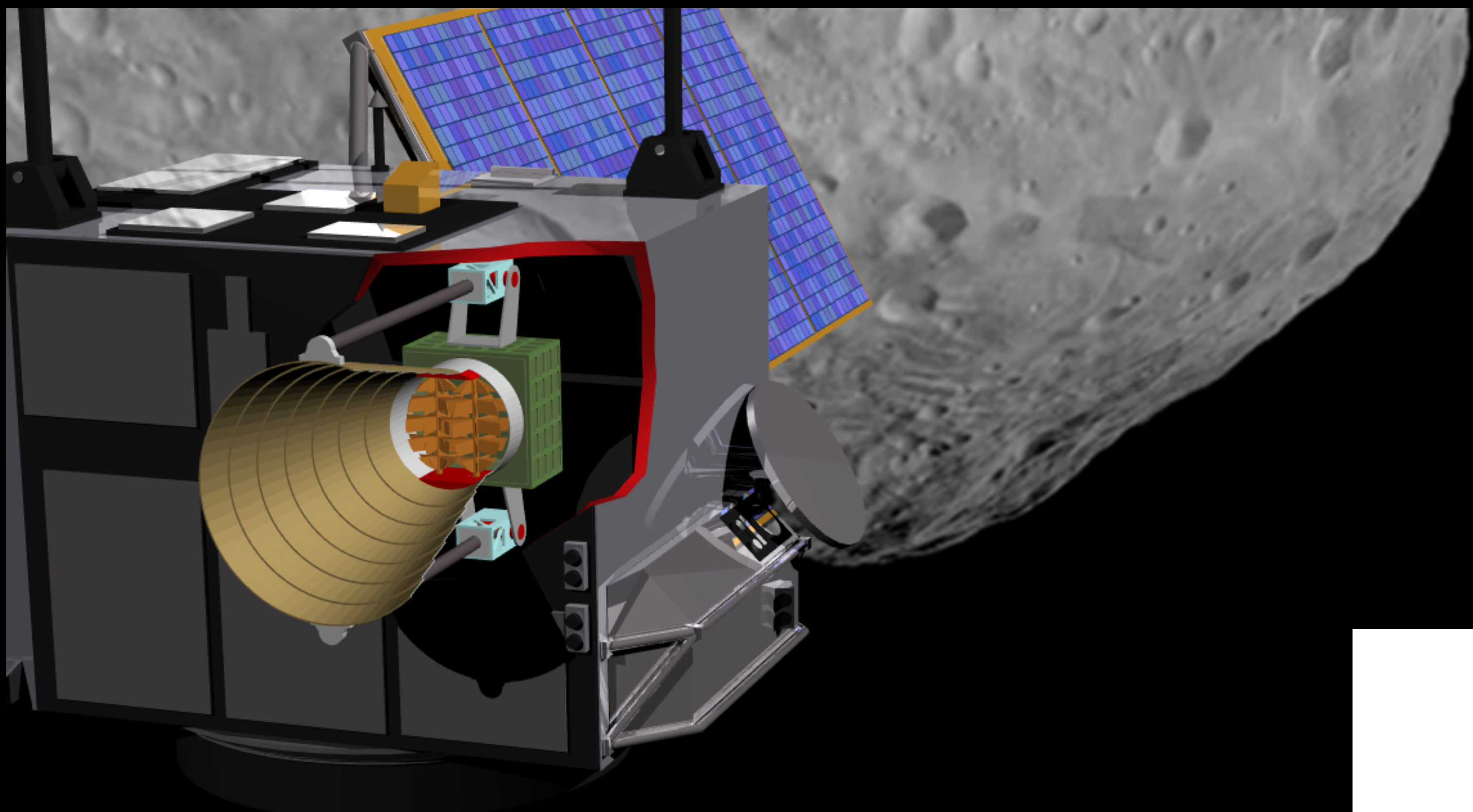


- Example case:
  - debris 10 m away, moving 14 cm/s laterally to FoV
- Relative state almost immediately acquired
  - Errors are are on the cm, sub mm/s level
  - 3σ uncertainties ~5 cm

Lofting Considerations

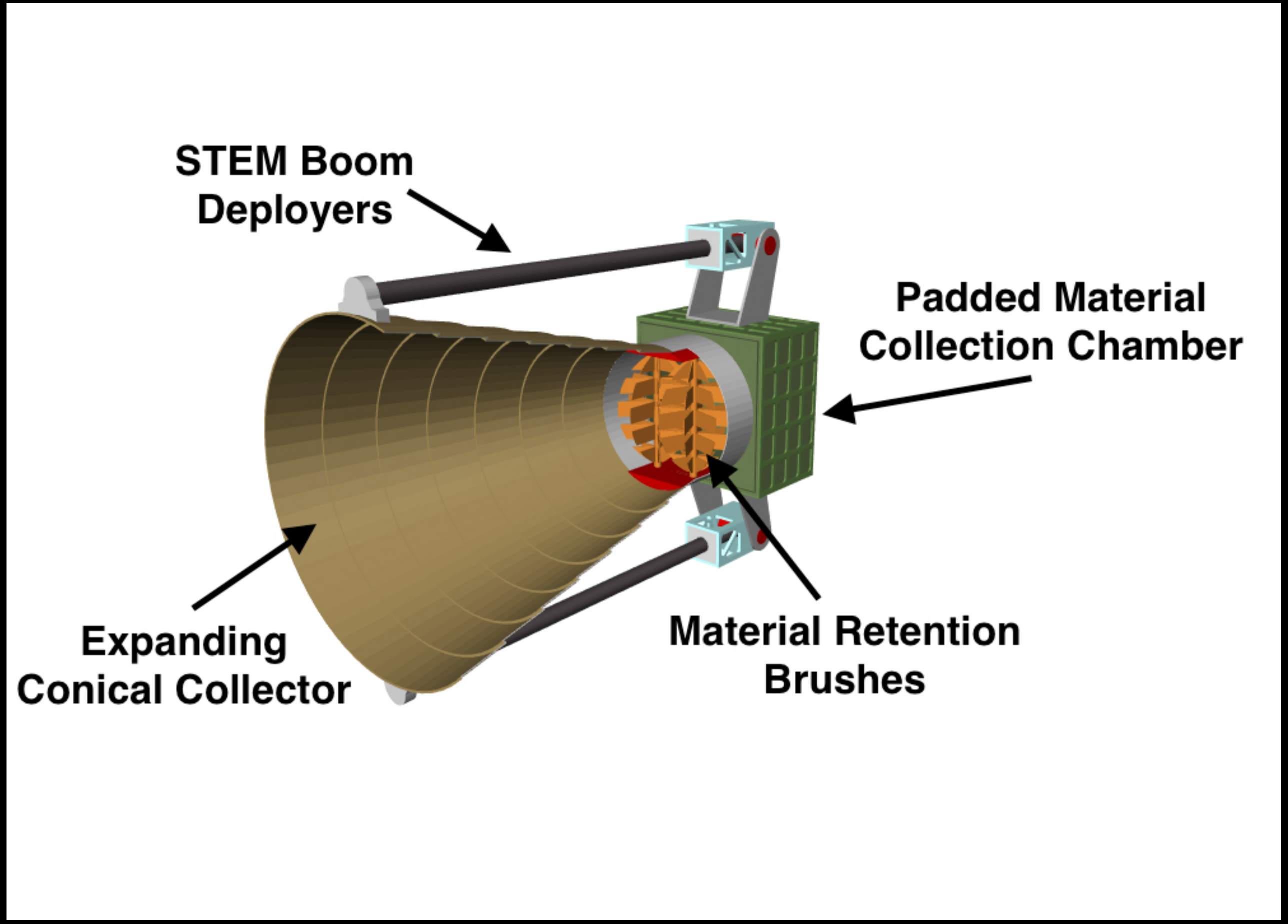
- Kinetic impactor or landed explosive are leading candidates
  - Hayabusa 2 kinetic impactor (2 kg copper, 2 km/s, 2-7 m crater)
  - BASiX blast pods (5 kg exlposives, 20 MJ, 2+ m craters)
- Only need very low surface relative speeds
  - all results tested here max out at 15 cm/s
- Most research in the asteroid community looks at hyper-velocity (~km/s) impacts for asteroid collision studies
  - similarly for planetary defense kinetic deflection research
- Need new research for slow speed impacts/disturbing
  - will get some of this data from OSIRIS-REx TAG

Capture Mechanism



Design work performed by
Altius Space Machines

- Preferred capture mechanism is an extendable cone with mechanical collection area
- Slow speeds allow mechanical capture without worry of significant danger to spacecraft
- Allows for downstream design for on-board characterization of debris if desired



Summary

- LoRS leverages the natural dynamics of the system instead of fighting them
  - Relatively cheap and easy to flyby/orbit, but dangerous and difficult to land
  - Allow SRP to sift material for free
- This architecture is robust to many of the uncertainties that currently plague resource utilization scenarios
  - Asteroid material properties, shape, gravity field
  - Uncertainty in lofting methods and resultant velocities
- Adaptive conops
  - e.g. material doesn't have to be collected after remote sensing
- Similarly this architecture can be used to prospect multiple locations
  - the main components of the system are not deployed to the surface
- Phase II work will focus on developing technologies to make its small, cheap, and repeatable
  - Autonomous GNC, sensing, conops
  - Continued work will not only enable LoRS prospecting missions, but will also develop technology that can be useful for many exploration missions

Acknowledgments

- CU
  - Ann Dietrich
  - Michael Van den Broeck
  - Alessandro Vanzella
- Advanced Space
  - Alex Rodriguez
  - Brandon Seifert
- Altius Space Machines
  - Jon Goff
  - Keith Drake
- NASA KSC

Questions?