Planetary Defense, Centaur Exploration, and a Mission Agnostic Probe for Small Bodies Missions

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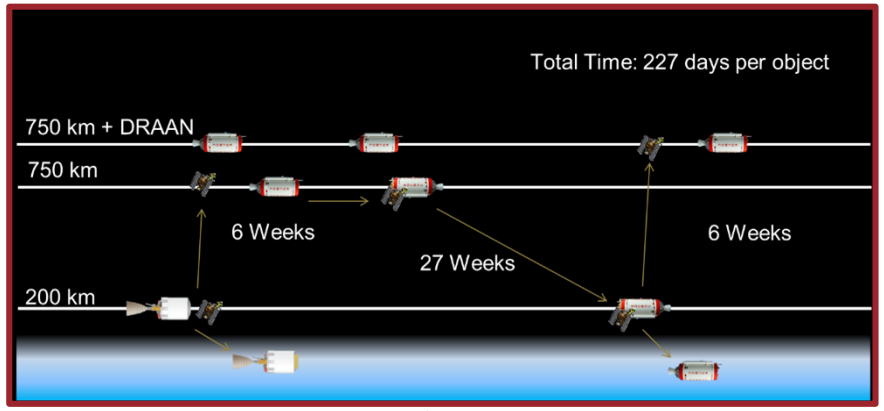
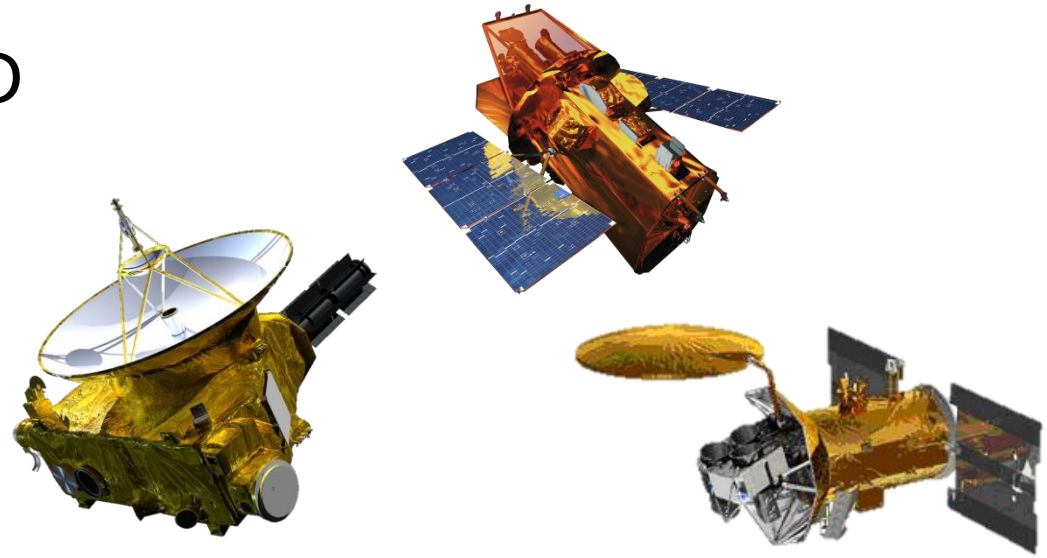
About Me

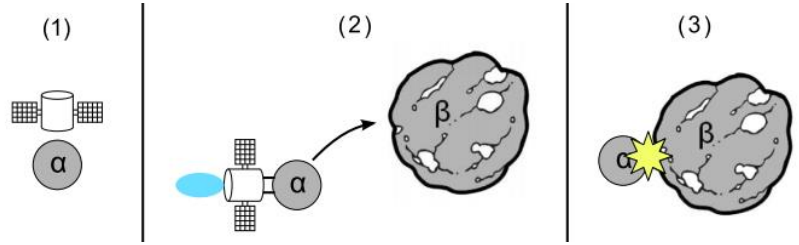
- **M.S. Aerospace Engineering**, UMD
  - Mission design for proposed LEO debris removal technologies
  - Developed MDO satellite design software
- **PhD, Aerospace Engineering**, UMD *(in progress)*
  - Automated trade space exploration for early concept spacecraft design
  - Develop generalized spacecraft modelling framework

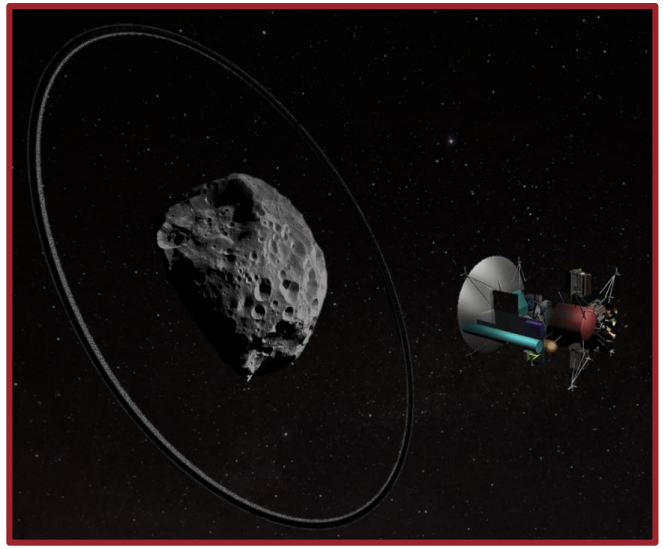




Small Bodies Work

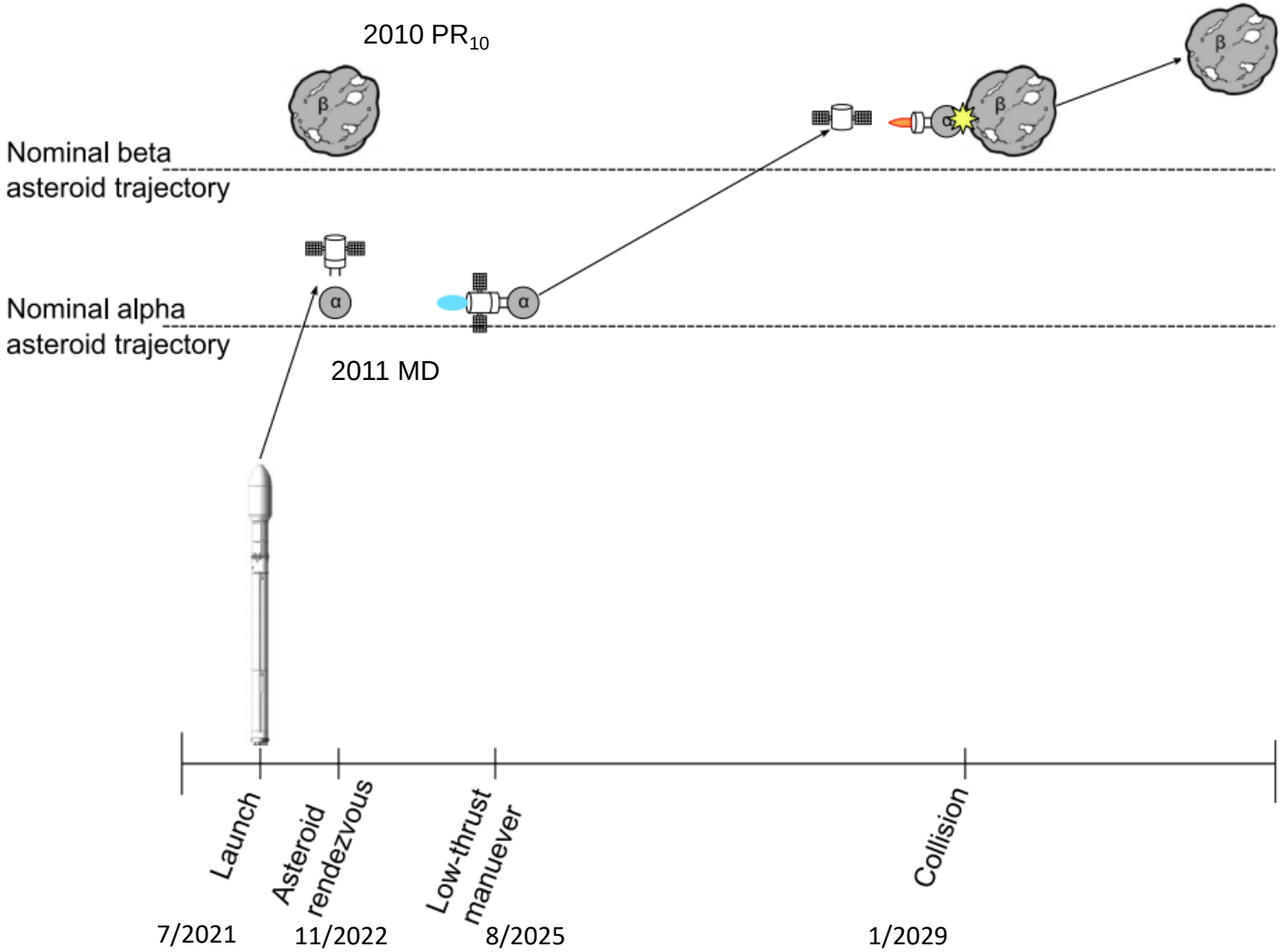
- **BILLIARDS: Planetary defense mission**
  - Kinetic impactor mission redirecting small NEO to collide with potentially hazardous asteroid (PHA)
- **Camilla: Centaur reconnaissance mission**
  - JPL Planetary Science Summer Seminar
  - Developed New Frontiers class mission to fly by Chariklo
- **Mission agnostic probe** (MAP) for small bodies characterization
  - Single spacecraft design to address many missions
  - 80% of the science for 1/4 the cost

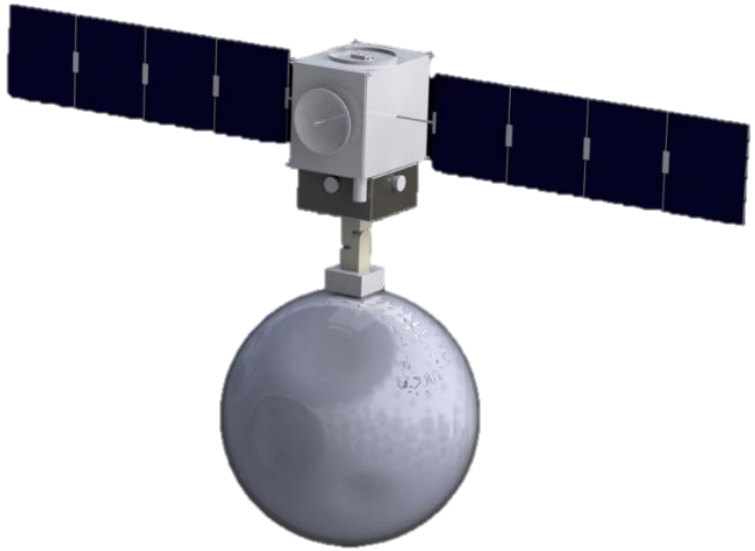




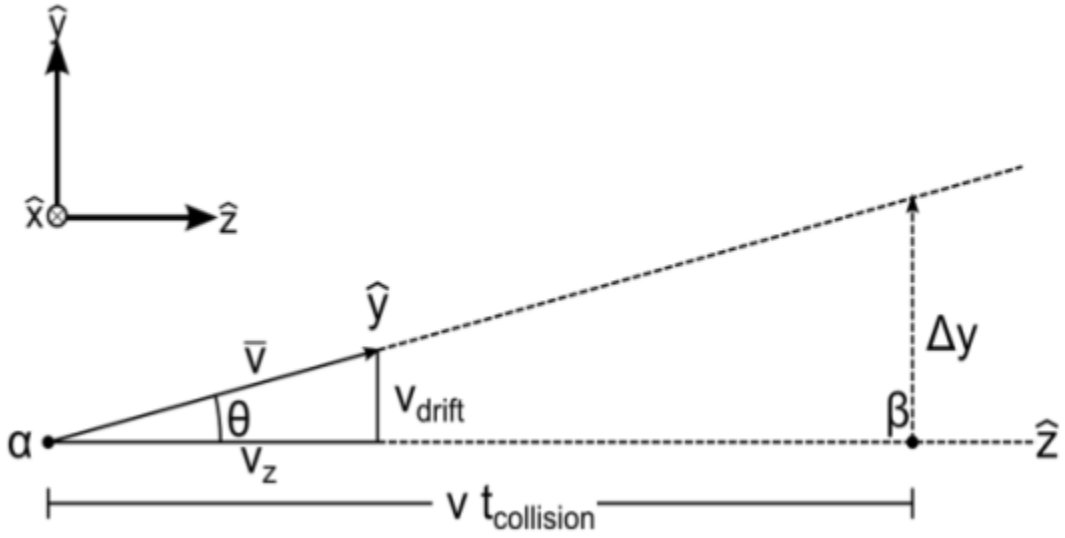
Credit: S. Howell et. al., 2017

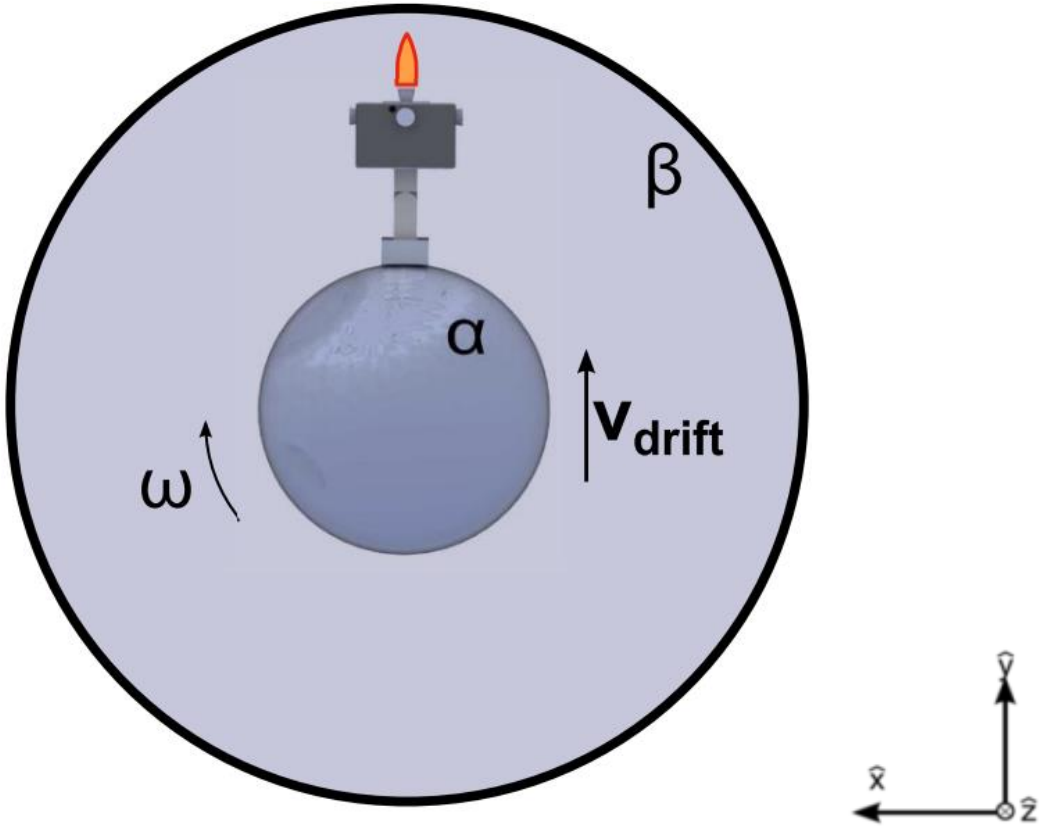
BILLIARDS


2010 PR10
Nominal beta asteroid trajectory
Nominal alpha asteroid trajectory
2011 MD
Launch
Asteroid rendezvous
Low-thrust manuever
Collision
7/2021
11/2022
8/2025
1/2029



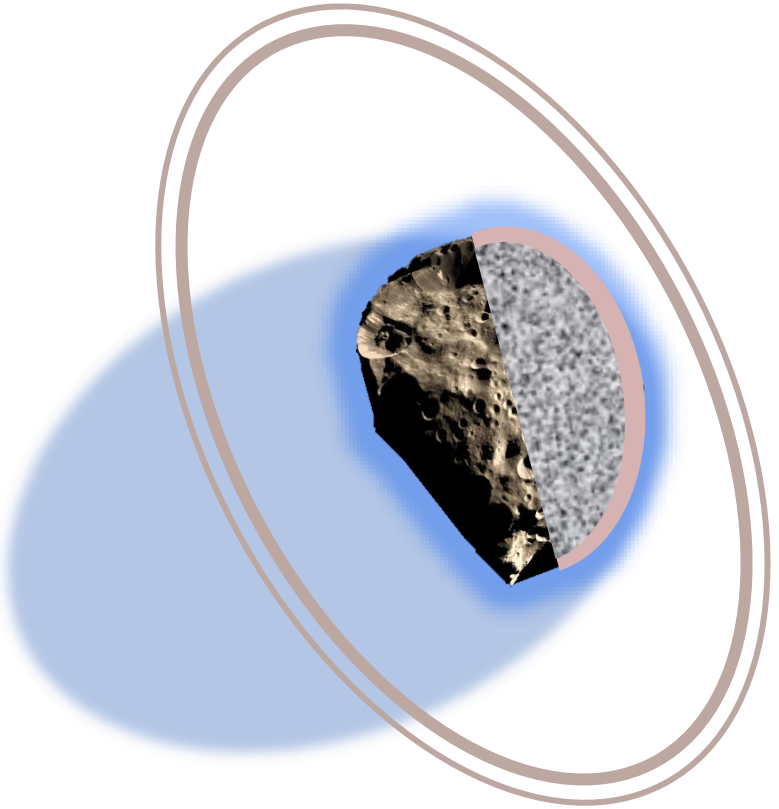
BILLIARDS – Terminal Guidance





Camilla

- **New Frontiers** class mission
- Launch in 2026
- Flyby in 2039
- **Science goals:**
  1. Determine surface processes and characteristics
  2. Investigate the formation mechanisms and lifecycle of complex systems
  3. Characterize surface and subsurface chemistry to constrain the origin of Centaurs within the solar system

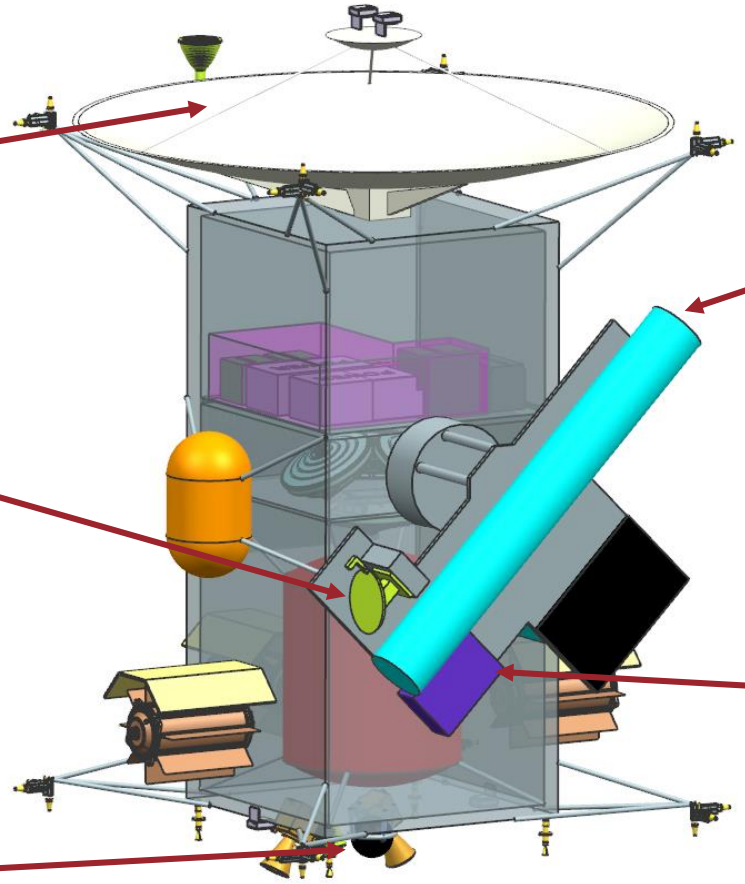


Camilla – Instrument Design

CERSE
- Radio science experiment
- Mass: < 1 kg
- Power: < 1 W

SMART
- Sub-mm radiometer
- Mass: 10 kg
- Power: 40 W
- Heritage: Rosetta MIRO

Halberd
- Tungsten impactor
- Mass: 100 kg
- Heritage: Deep Impact



CAMIS
- Visible/IR imager
- 300-900 nm coverage (visible)
- 0.9-5 μm coverage (IR)
- Mass: 52 kg
- Power: 29 W
- Heritage: Deep Impact HRI

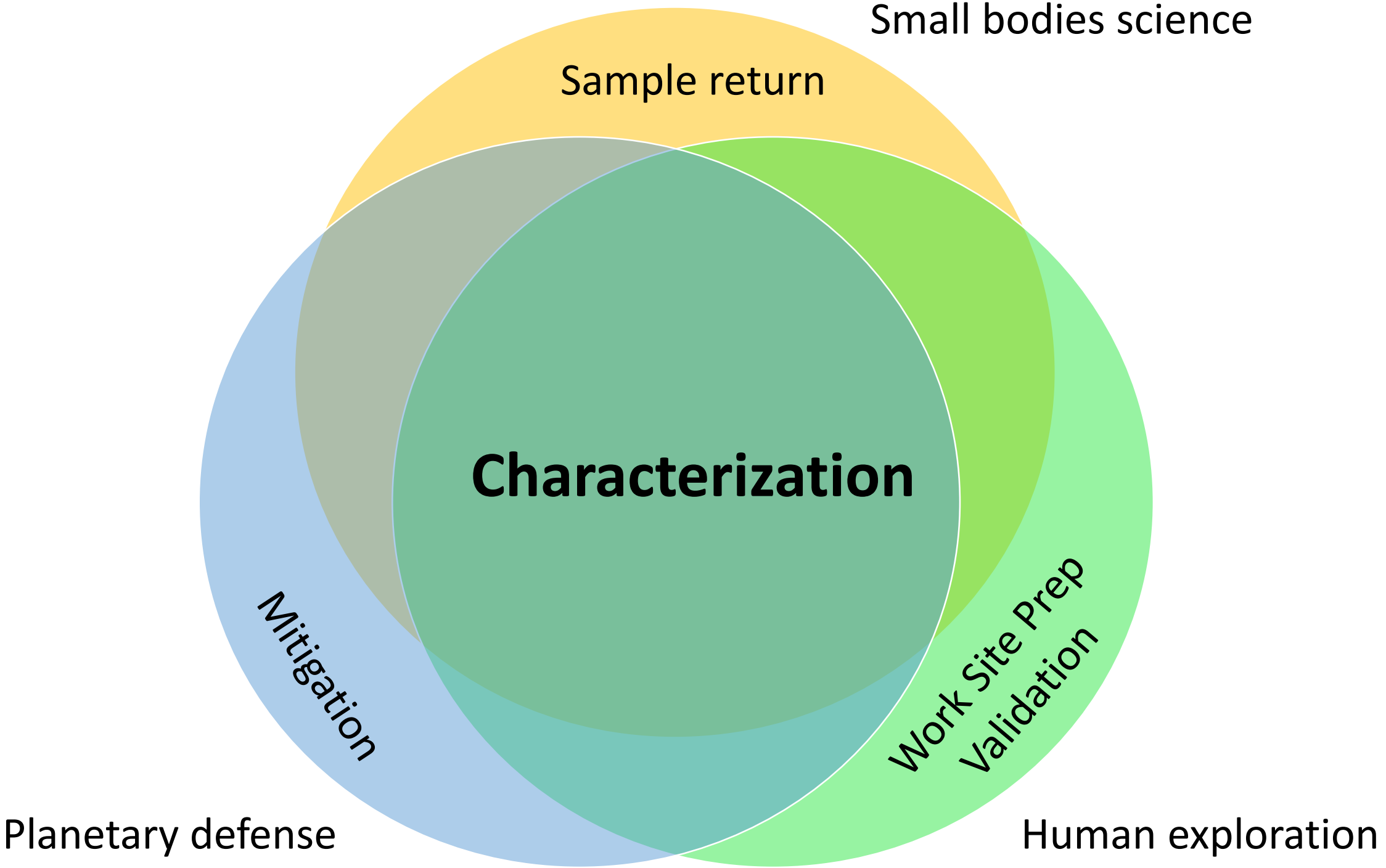
COEUS
- UV spectrometer
- 50-185 nm coverage
- Mass: 4.4 kg
- Power: 4 W
- Heritage: New Horizons ALICE

The Demand for Small Bodies Missions

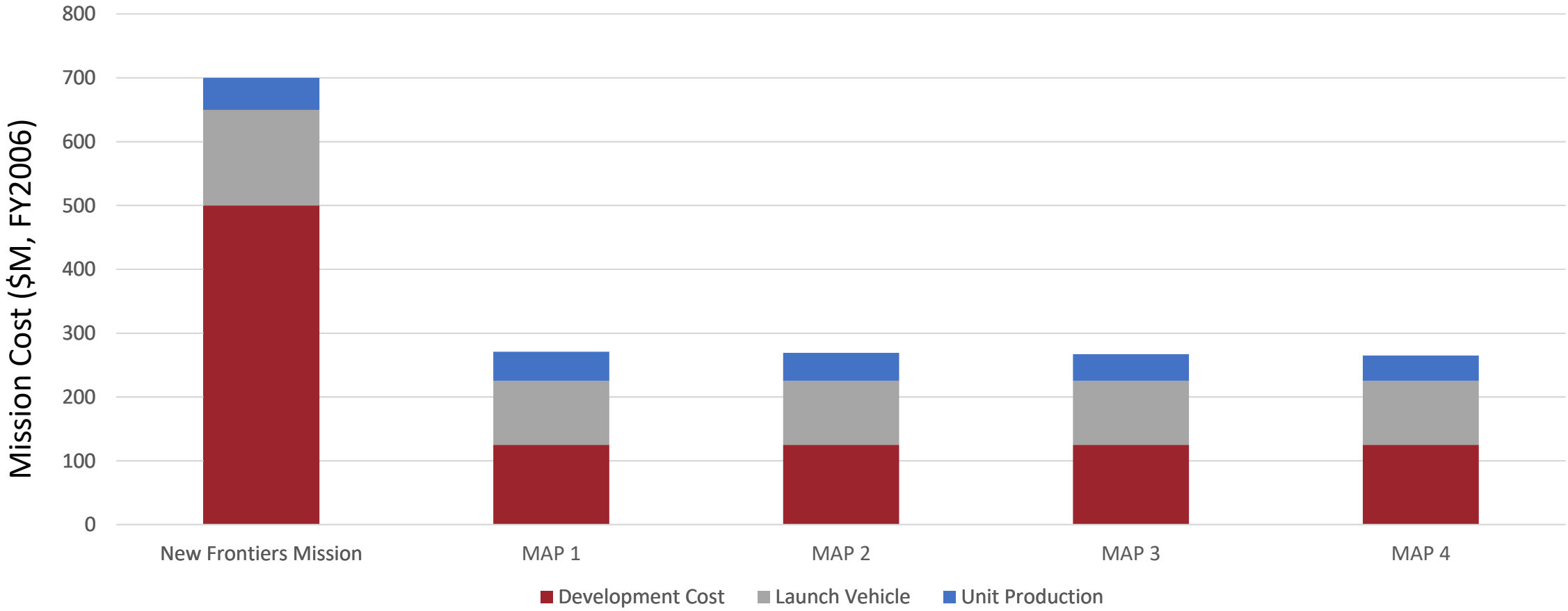
• **Planetary science** – 13 Proposals for Discovery 13/14 at SBAG 13	2 out of 13 proposals selected

• **Planetary defense** - National Near-Earth Object Preparedness Strategy and Action Plan:
  • Assess technologies and concepts for rapid-response NEO reconnaissance missions
  • Create plans for the development, testing, and implementation of NEO reconnaissance mission systems
	No missions currently funded

• **Human NEO exploration** - Robotic precursors to characterize target bodies	No missions currently funded


Small bodies science
Sample return
Characterization
Mitigation
Work Site Prep
Validation
Planetary defense
Human exploration

MAP – The Mission Agnostic Probe



What's needed now

Prioritized list of small bodies of interest

- Trajectory analysis
- Spacecraft mass constraints
- Space environment defined

Science and measurement objectives

- Instrument design
- Instrument operating requirements

Notional spacecraft/ program design

MAP: Conclusion

- 80% of the science for 1/4 the cost
- Designed with science in mind, but addresses all 2016 SBAG goals
- Consistent measurements from identical instruments
- Allows rapid response for PHA characterization and new missions of opportunity

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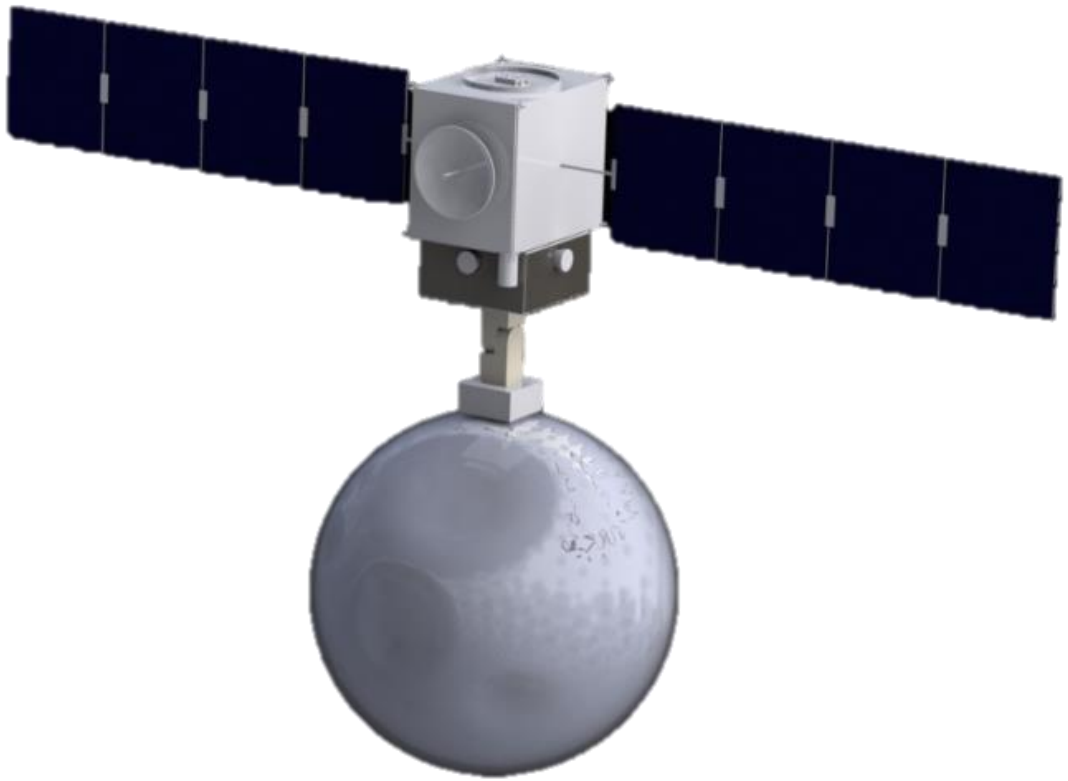
References

- Smith, E. S., Sedwick, R. J., Merk, J. F., & McClellan, J. (2013). Assessing the potential of a laser-ablation-propelled tug to remove large space debris. *Journal of Spacecraft and Rockets*, *50*(6), 1268-1276.
- Marcus, M. L., & Sedwick, R. J. (2017). Low Earth Orbit Debris Removal Technology Assessment Using Genetic Algorithms. *Journal of Spacecraft and Rockets*, *54*(5), 1110-1126.
- Marcus, M. L., Sloane, J. B., Ortiz, O. B., & Barbee, B. W. (2017). Planetary Defense Mission Using Guided Collision of Near-Earth Objects. *Journal of Spacecraft and Rockets*, *54*(5), 985-992.
- Howell, S. M., Chou, L., Thompson, M., Bouchard, M. C., Cusson, S., Marcus, M. L., ... & Eggl, S. (2018). Camilla: A centaur reconnaissance and impact mission concept. *Planetary and Space Science*, *164*, 184-193.

Backup Slides

BILLIARDS

- Instrumentation module
  - Dry mass: 691 kg
  - Xenon: 450 kg
  - N_2H_4: 50 kg
  - Total mass: **1191 kg**
- Terminal guidance module
  - Dry mass: 659 kg
  - Propellant: 600 kg
  - Total mass: **1259 kg**
  - Total ΔV: 16 m/s capable
- Combined spacecraft:
  - Total mass: 2450 kg
  - Mission cost: $997M (FY2016)



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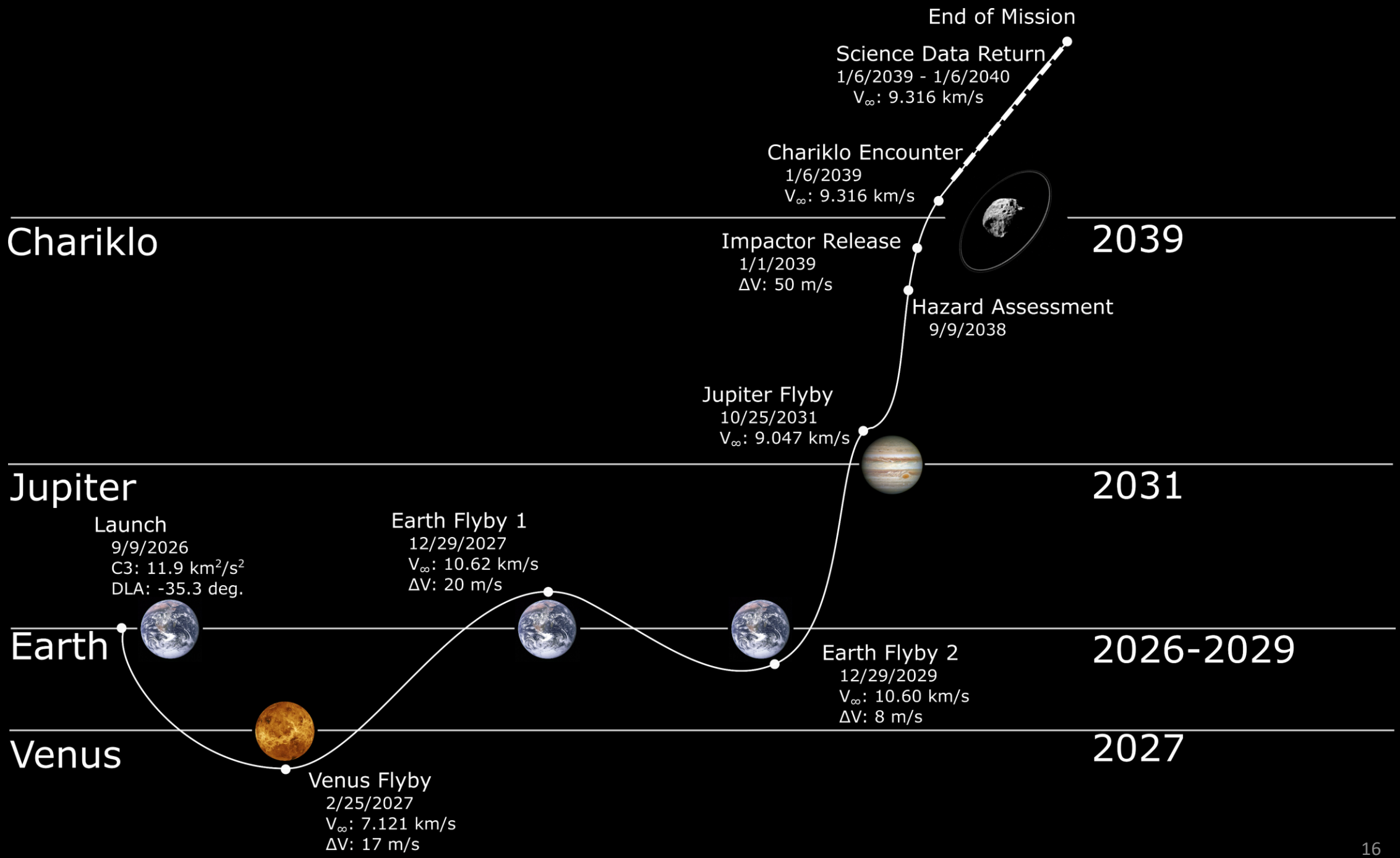
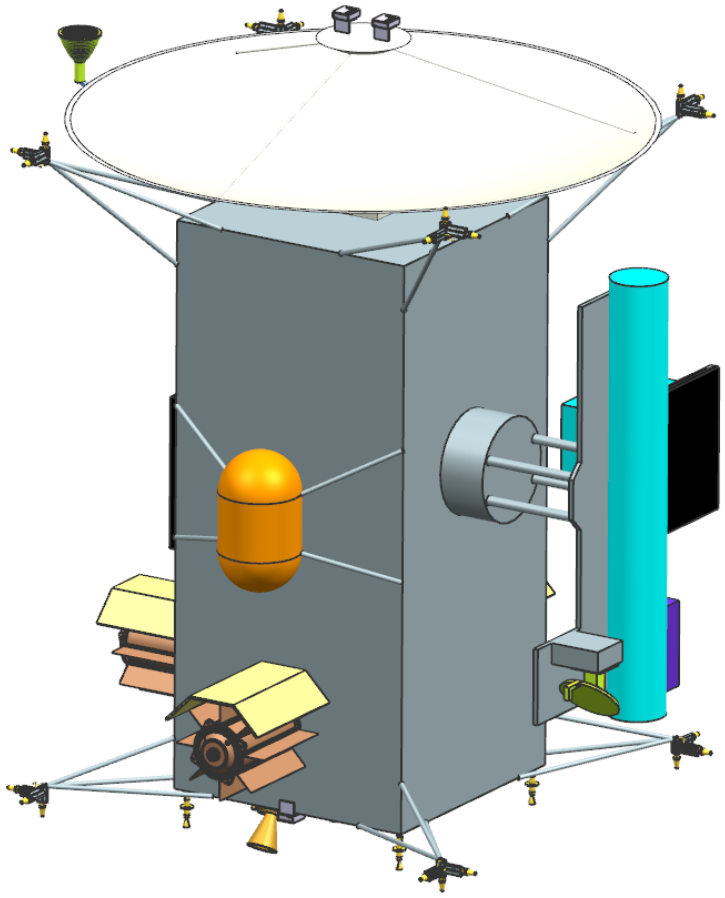

End of Mission
Science Data Return
1/6/2039 - 1/6/2040
V∞: 9.316 km/s
Chariklo Encounter
1/6/2039
V∞: 9.316 km/s
Chariklo
2039
Impactor Release
1/1/2039
ΔV: 50 m/s
Hazard Assessment
9/9/2038
Jupiter Flyby
10/25/2031
V∞: 9.047 km/s
Jupiter
2031
Launch
9/9/2026
C3: 11.9 km²/s²
DLA: -35.3 deg.
Earth Flyby 1
12/29/2027
V∞: 10.62 km/s
ΔV: 20 m/s
Earth
2026-2029
Earth Flyby 2
12/29/2029
V∞: 10.60 km/s
ΔV: 8 m/s
Venus
2027
Venus Flyby
2/25/2027
V∞: 7.121 km/s
ΔV: 17 m/s

Camilla Spacecraft Design

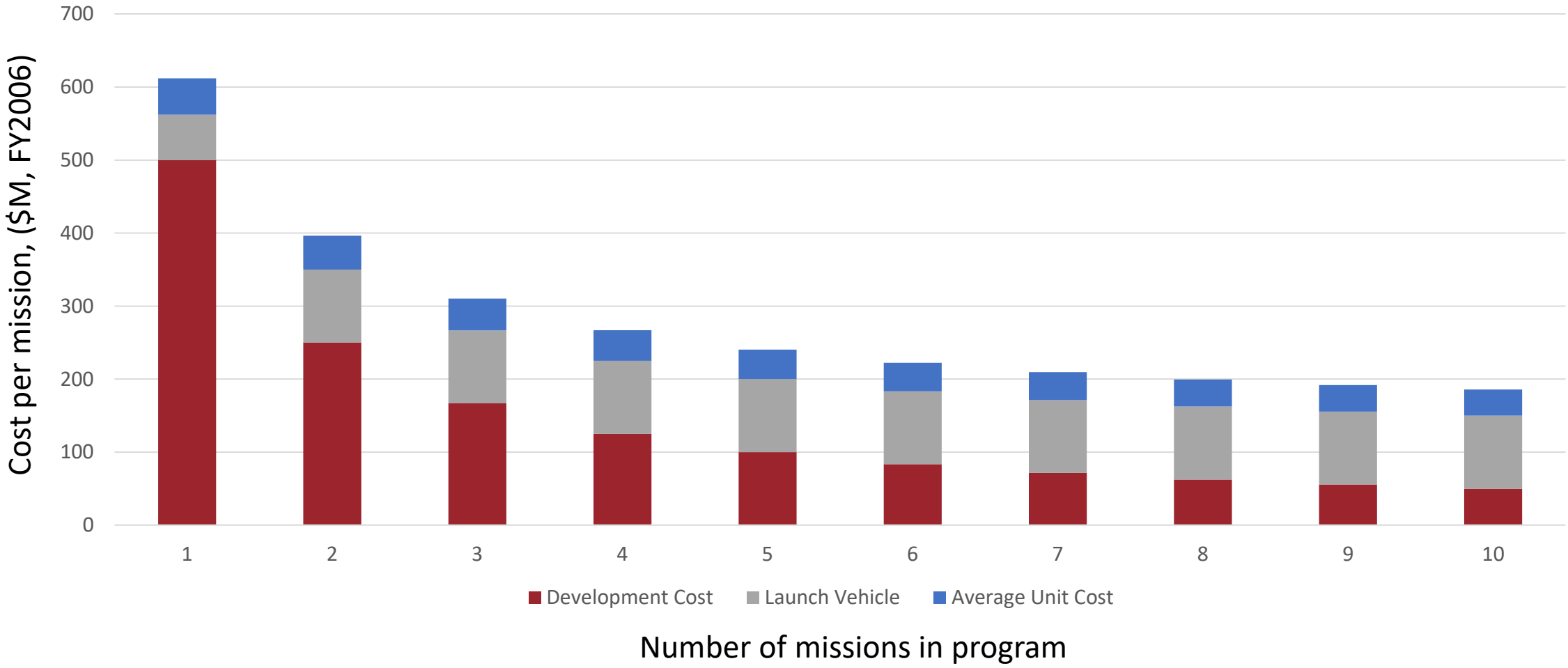


- Power:
  - 3 MMRTGs – 210 W
  - 8 kWh secondary batteries for high power modes
- Propulsion:
  - Monopropellant chemical thrusters
  - Total Δv capability – ~400 m/s
  - ~420 kg monopropellant
- Attitude control:
  - Reaction wheels for primary pointing – driven by impactor release
  - Monopropellant ACS to allow 180º slew in 90 seconds
- C&DH – 65 Gb of data expected from encounter
- Total wet mass at launch – 1913 kg

Mission Objectives

- Planetary science
  - Chemically and physically characterize small bodies of scientific interest
  - Sample return
- Planetary defense
  - Characterize PHAs
  - Develop mitigation spacecraft
  - Long term and rapid response
- Human NEO exploration - Robotic precursors to characterize target bodies
  - Characterize targets of interest for human exploration
  - Send robotic precursor missions to validate trajectories/environment, prep work sites

MAP – The Mission Agnostic Probe



Science Payload

- Based on highest priority targets
- Aim to achieve 80% of science vs. custom mission
- Example instrument package:
  - Wide angle:
    - Multispectral imager
    - Multiband spectrometer
  - Narrow angle camera
  - Radio science