

POLITECNICO
MILANO 1863



Spaceborne flight formation, dynamics, and navigation

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19 June 2025

OUTLINE

- Introduction
- Mission design
- Notable cases
- Main challenges

Space-related activities at Polimi

Teaching

BSc in Aerospace
Engineering

550

Undergraduate
students

MSc in Space
Engineering

200

Graduate
students

PhD in Aerospace
Engineering

50

PhD students

*Yearly enrollment in AY 2024/2025
+ classes in other courses (EO, telecom, etc.)*

Research

- 1 Department (70 faculty members) entirely devoted to aerospace research (only one in Italy)
- Space-related research also spread in other departments

Innovation

- Home of one of ESA's BICs (Business Incubation Center)
- Joint Research Platforms (JRP) with main national players (ASI, Leonardo, TAS-I, SITAEL, etc.)

Third mission

- Home of the Space Economy Observatory
- Contributes to shape space policy at national and EU level



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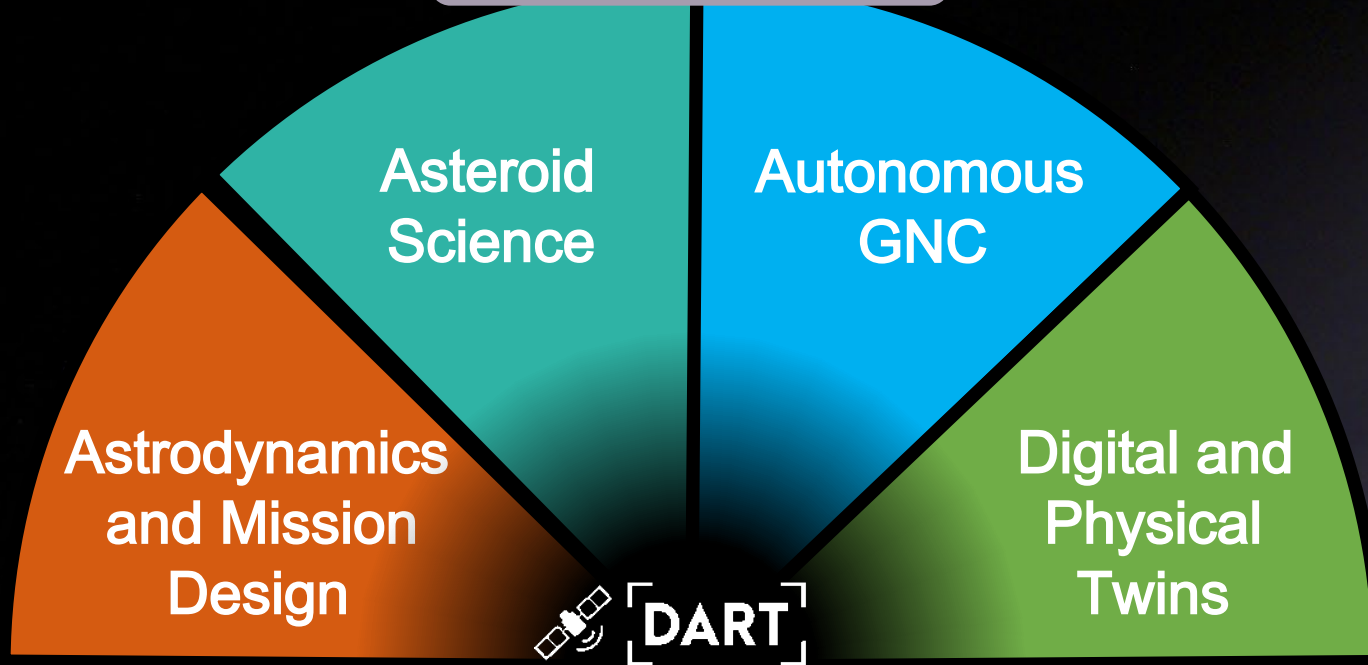


[DART] Group

The DART Lab

- Deep-space Astrodynamics Research and Technology Laboratory
- 45 full time researchers (7 faculty members, 38 postdoc/PhD/RA)

Main activities



Main projects



Hera's Milani



RAMSES' RG\$



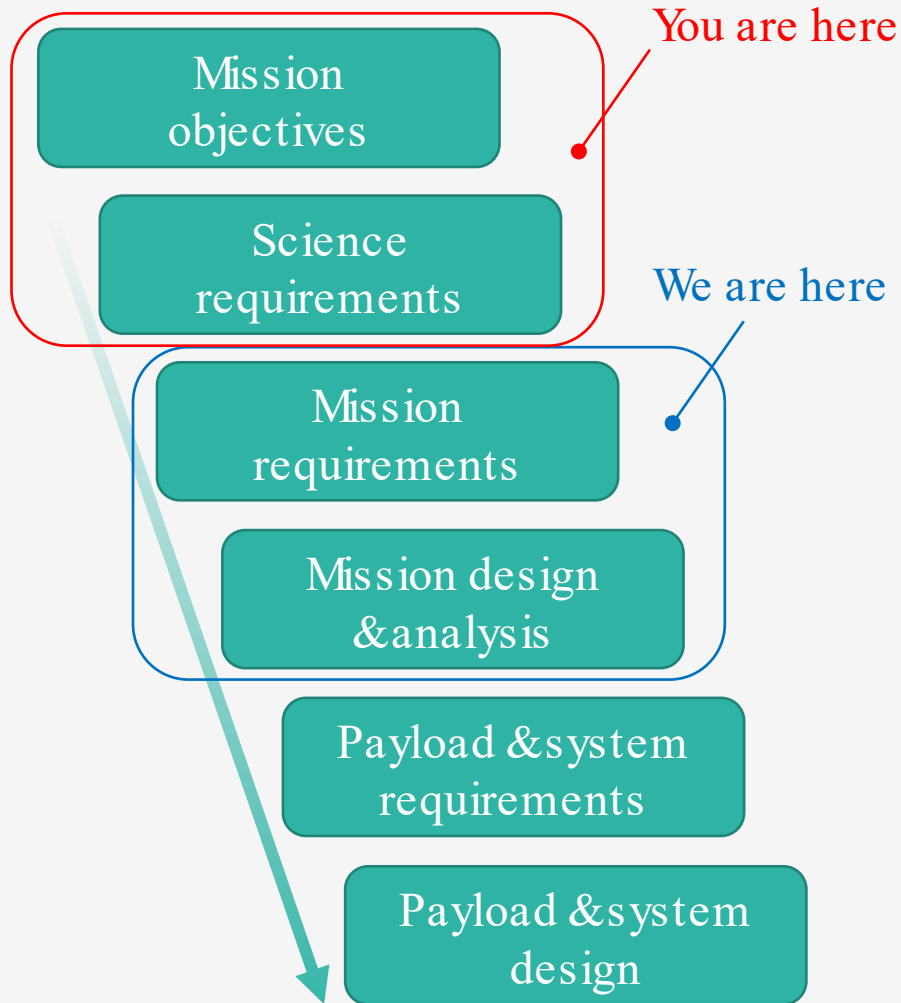
LUMIO



European Research Council
Established by the European Commission

- *EXTREMA (CoG)*
- *TRACES (StG)*
- *SENSE (PoC)*
- *GUIDO (PoC)*
- *AXESS (PoC)*

Mission design

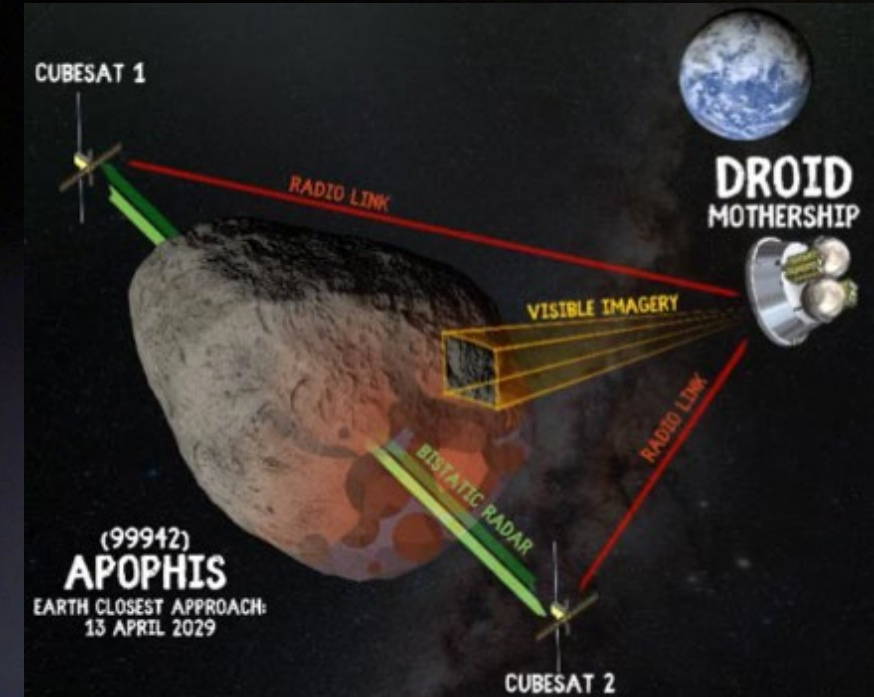
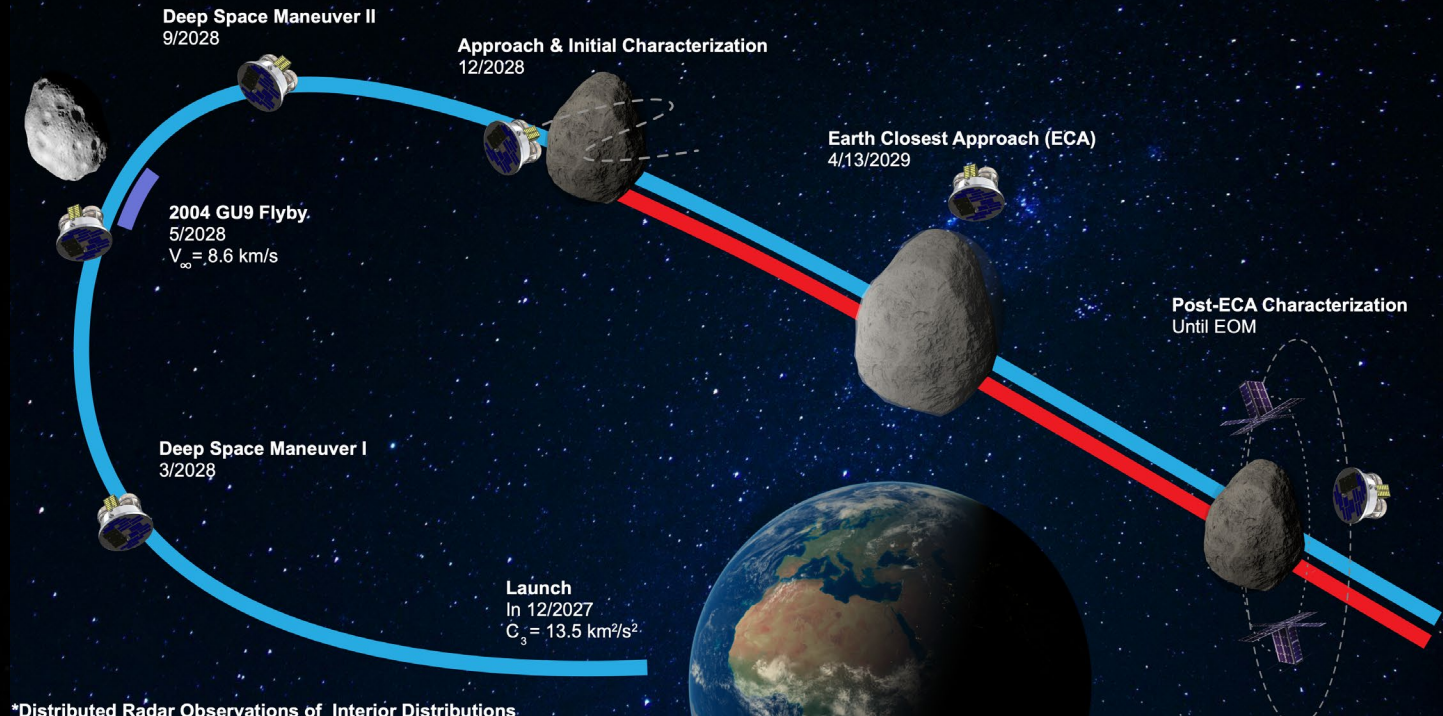


- **Mission design** to plan and organize a space mission from concept to execution
 - Output: Mission profile, phases, conops, etc.
 - How: Paper and pencil
- **Mission analysis** analysis of satellite orbits to verify mission requirements and define payload & system requirements
 - Output: Geometric, knowledge, dispersion analysis, delta-v budget, etc.
 - How: COTS or custom, sophisticated tools depending on the mission

Notable case 1: DROID

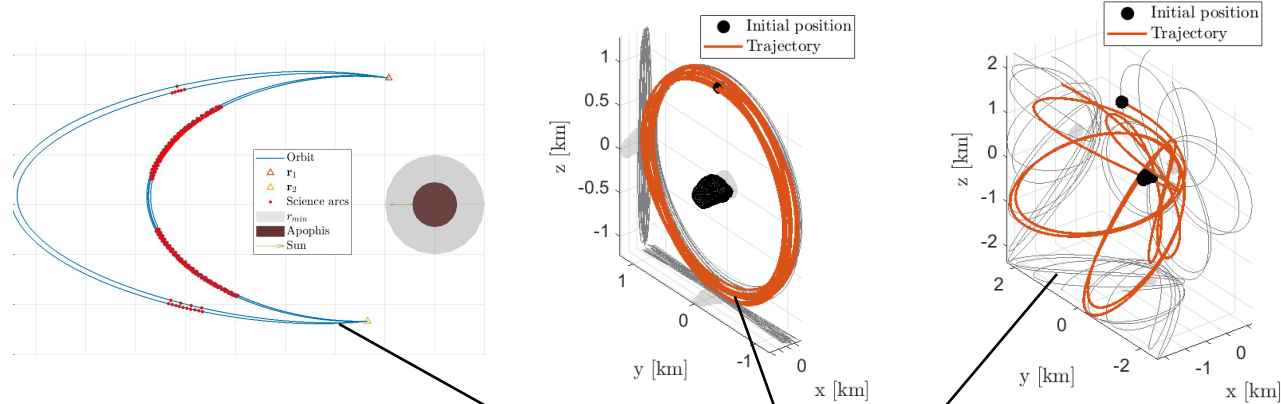
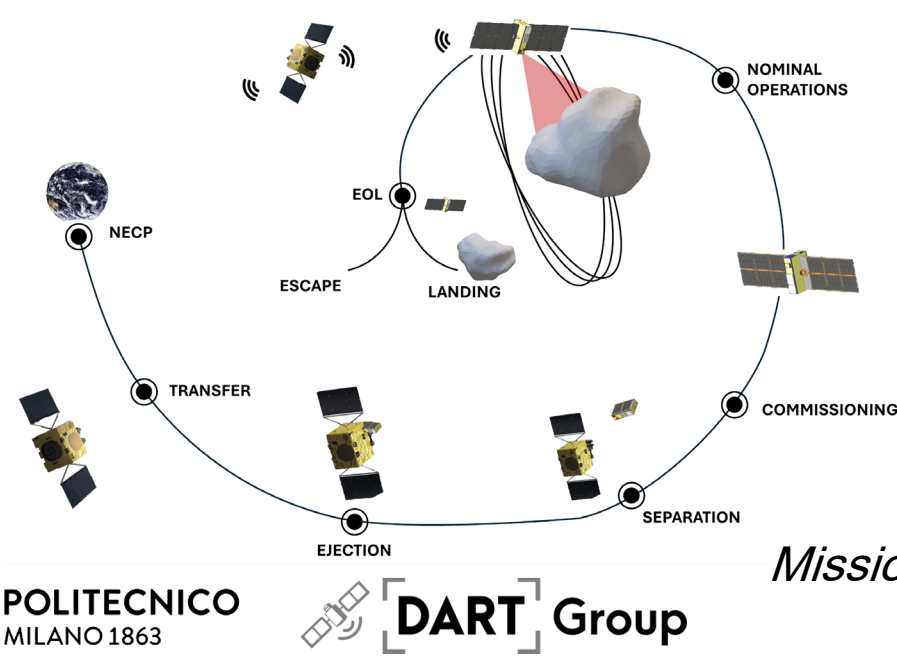
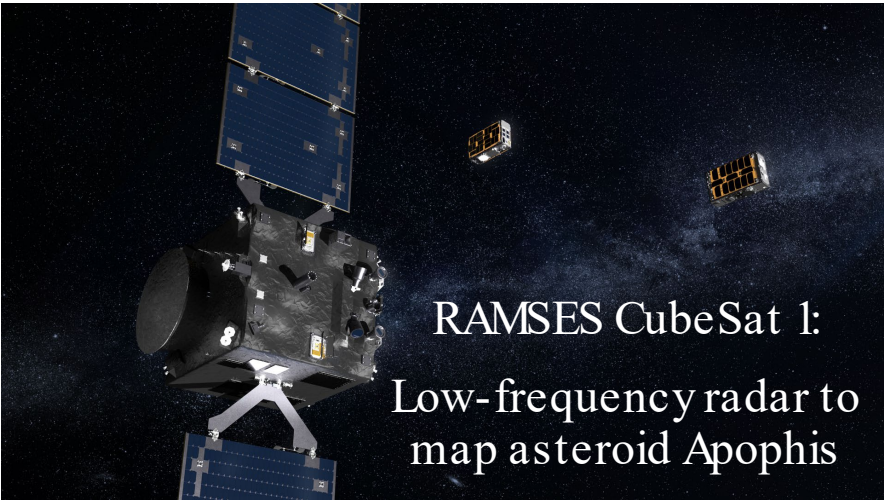
Credits: JPL Credits: C. A. Raymond et al

DROID Shepherding Apophis Through Close Approach; Cooperative Inspection to Characterize Interior and Exterior



- Mothership + 2 CubeSats
- Low-frequency radar
- Mono & bistatic observations
- Low orbits used

Notable case 2: RG\$

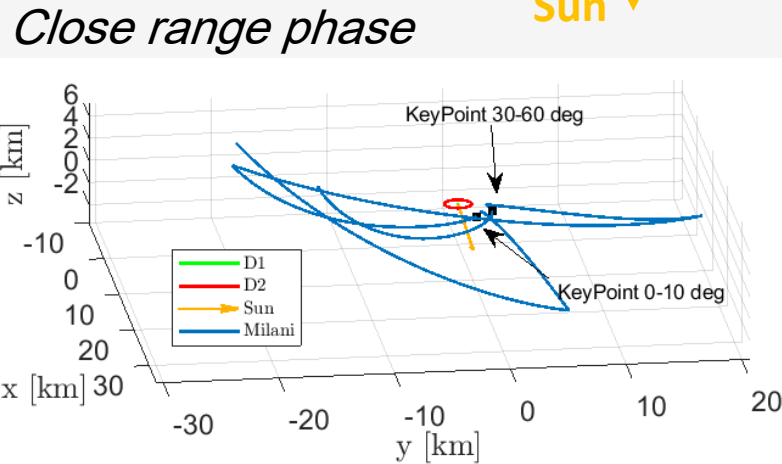
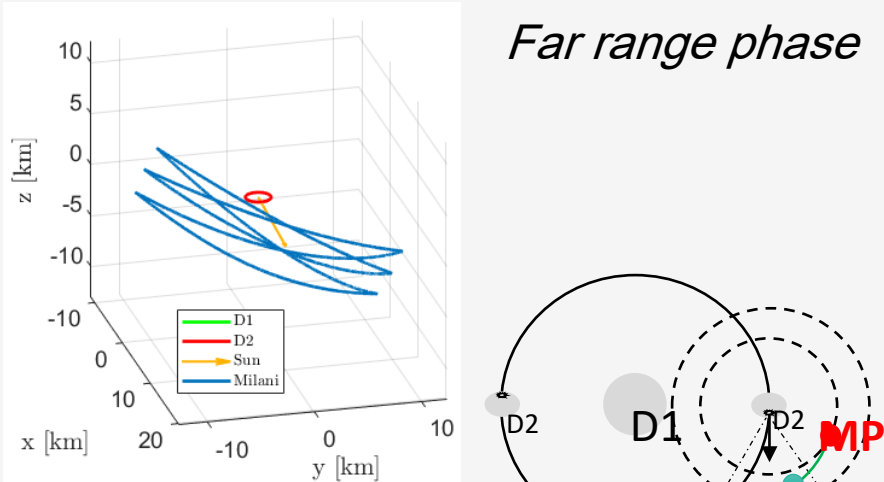
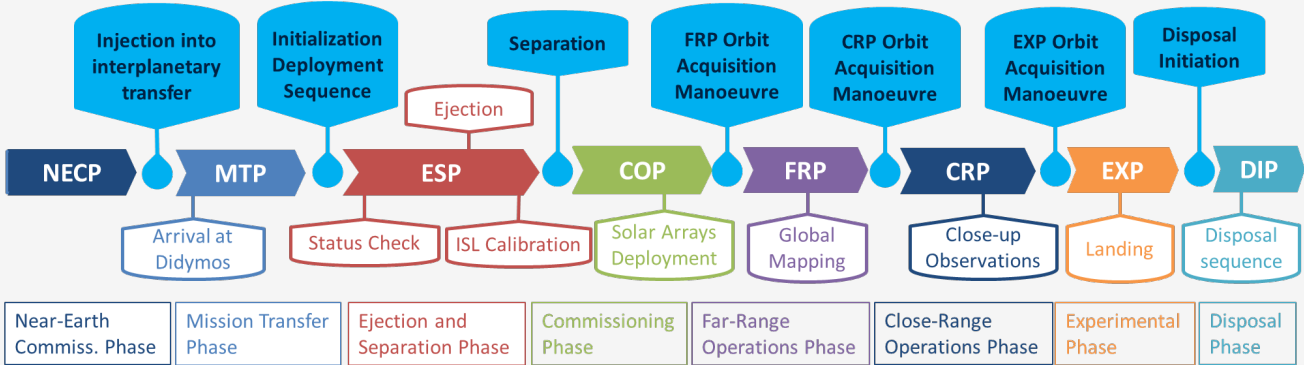
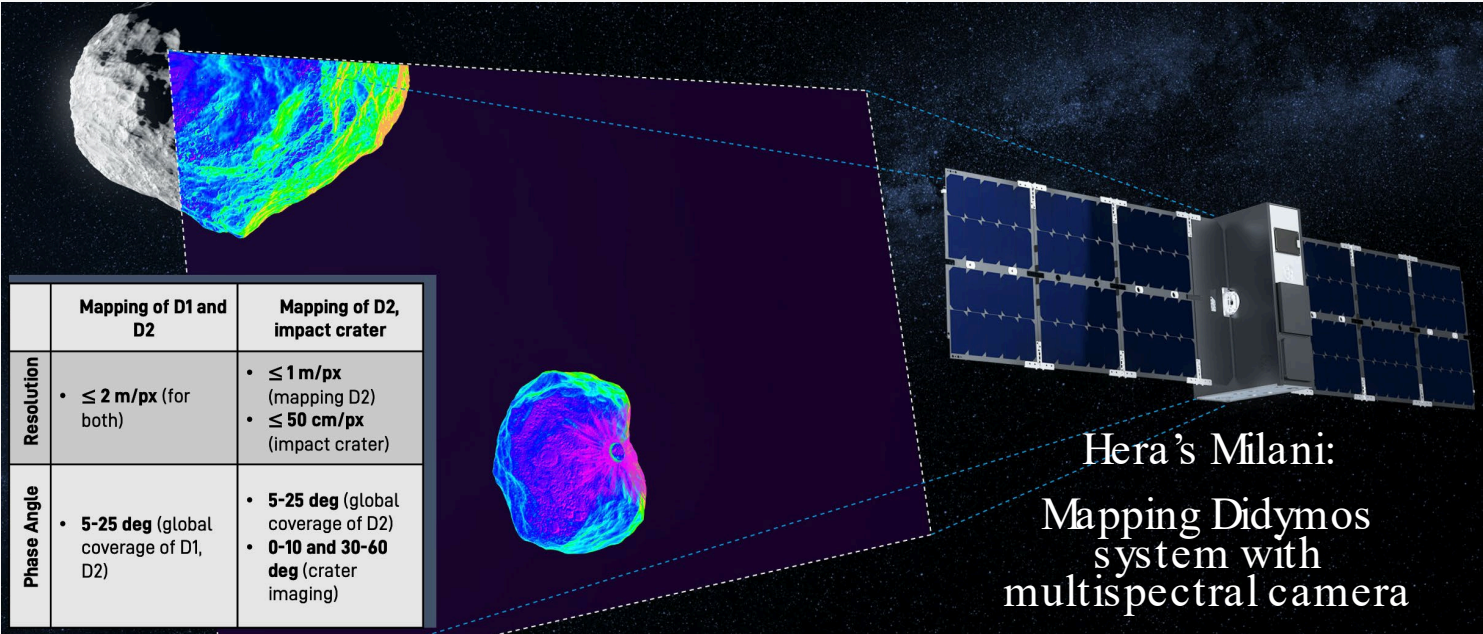


		Hyperbolic arcs	SSTO	RTO	Hovering (Sun)	Hovering (Earth)
Science w/ radar	Time	< 50%	100%	~100%	Depends on the distance	Depends on the distance
	Relative velocity	Good	Low	Discrete	Low	Low
Science w/ camera	Phase angle	<90 deg	>90 deg	(60, 120) deg	≈0 deg	>90 deg
	Distance	Can vary	Fixed	Can vary	Fixed	Fixed
Operations	Time between maneuvers	<3 d	Only SK needed	Only SK needed	<2 d	<2 d
Navigation	Phase angle	<90 deg	>90 deg	(60, 120) deg	≈0 deg	>90 deg
	Distance	>2 km	<2 km	(0.5, 2.5) km	(1, 5) km	(1, 5) km
Safety	Against escape or impact	Inherently safe trajectories	Safe trajectories	Safe trajectories	Escape is likely	Escape is likely
Simplicity	Compliant w/ 4-3-4-3 pattern	Partly 4-day arcs to be split	Yes	Yes	No	No
Robustness	Against uncertainties	Robust far from the body	Robust	Robust	Robust	Robust
Monthly Cost		≈1.5 m/s	<1 m/s	<1 m/s	>2.5 m/s	>2.5 m/s

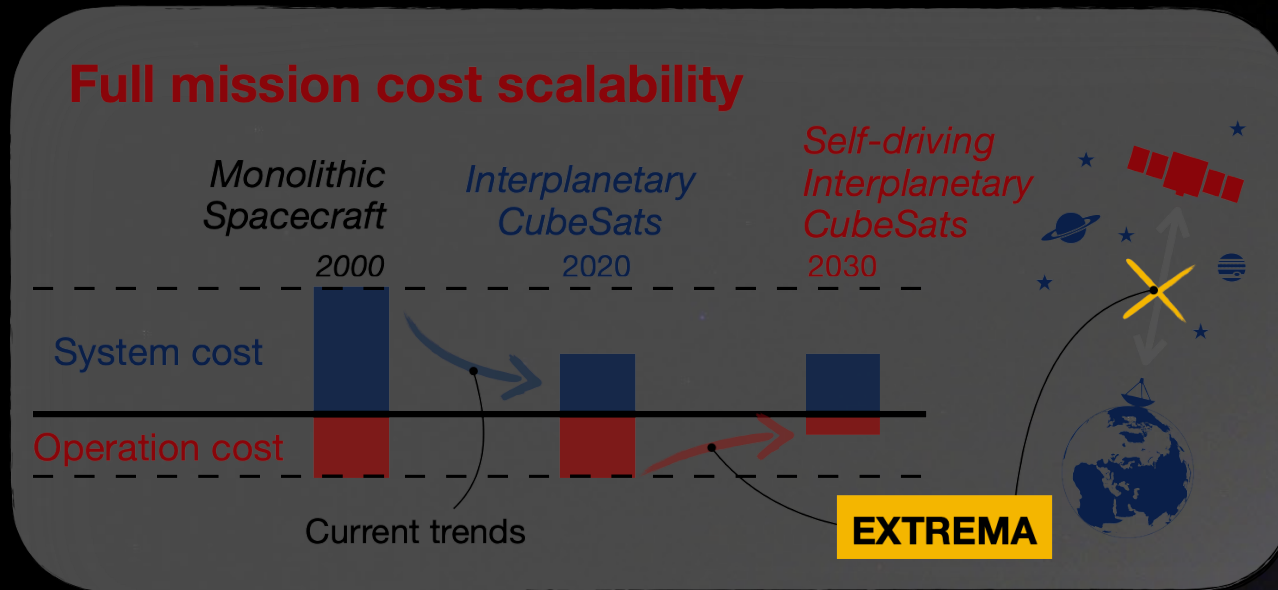
Mission profile

Operative orbit tradeoff

Notable case 3: Milani



Main challenges and trends



Interplanetary CubeSats GNC: an emerging, yet challenging topic.

Hints for future research:

- Reduce on-ground operations to bear minimum
- Favour full mission cost scalability

- Autonomous navigation
- Autonomous guidance

EXTREMA

To what extent can we navigate the solar system free of human supervision?

The Engineering Extremely Rare Events in Astrodynamics for Deep-Space Missions in Autonomy (EXTREMA) project wants to **challenge** and **revolutionize** the current paradigm under which spacecraft are piloted in the interplanetary space.



EXTREMA



European Research Council
Established by the European Commission

Goal: To enable deep-space CubeSats with autonomous GNC capabilities

Pillar 1
Autonomous Navigation

Experiment 1
EXTREMA Optical Facility

Pillar 2
Autonomous Guidance

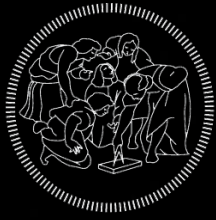
Experiment 2
EXTREMA Thrust Test Bench

Pillar 3
Autonomous Ballistic Capture

Experiment 3
Ballistic Capture Corridors

EXTREMA Simulation
Hub (ESH)

IMPACT



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