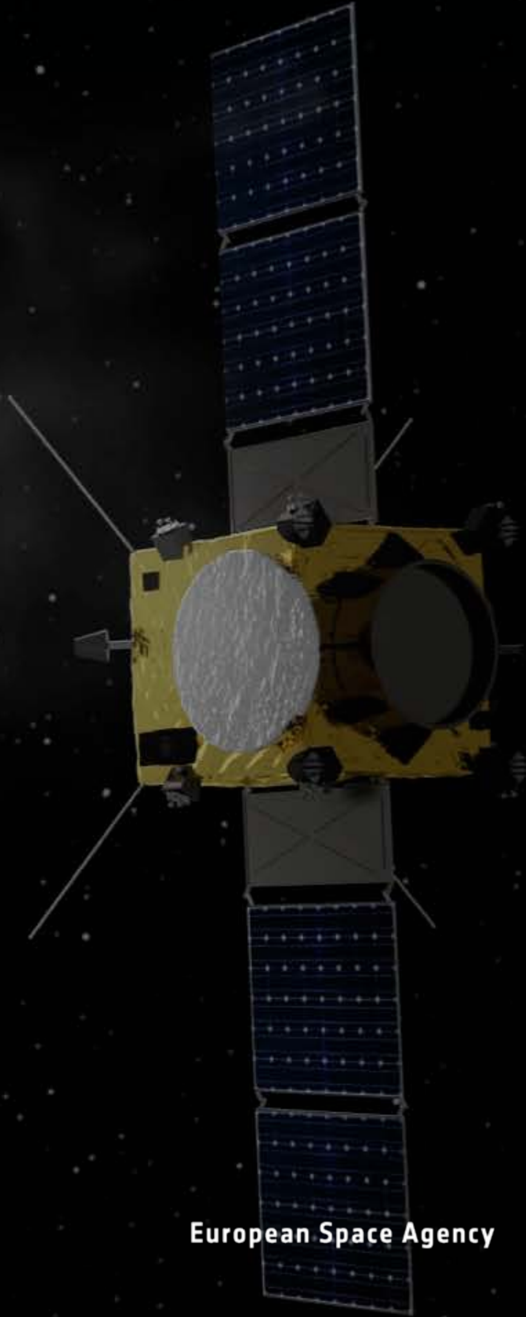
aim

esa

→ ASTEROID IMPACT MISSION

Small lander and cubesats on ESA's Asteroid Impact Mission – a GNC perspective

M. Casasco
J. Gil Fernandez
G. Ortega
I. Carnelli



European Space Agency

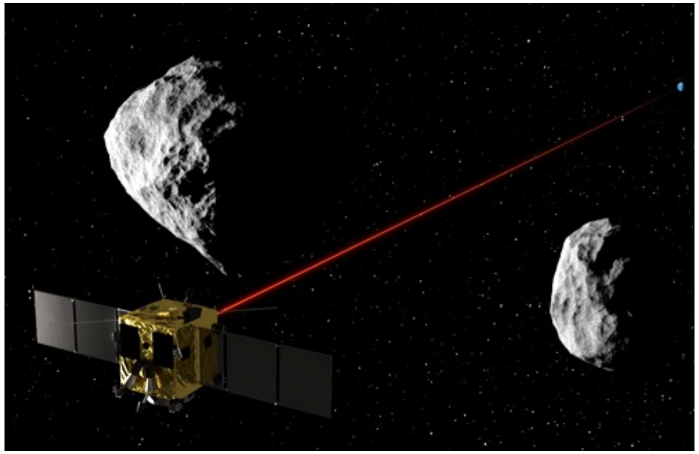
ASTEROID IMPACT MISSION (AIM)

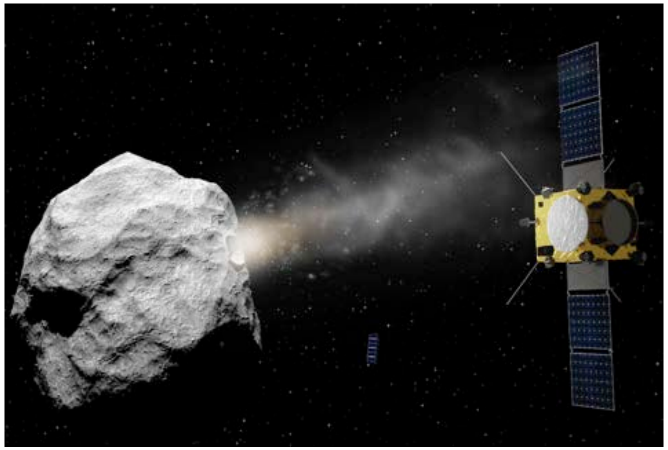
Small mission of opportunity to explore and demonstrate technologies for future deep-space missions while addressing planetary defense objectives and performing asteroid scientific investigations.

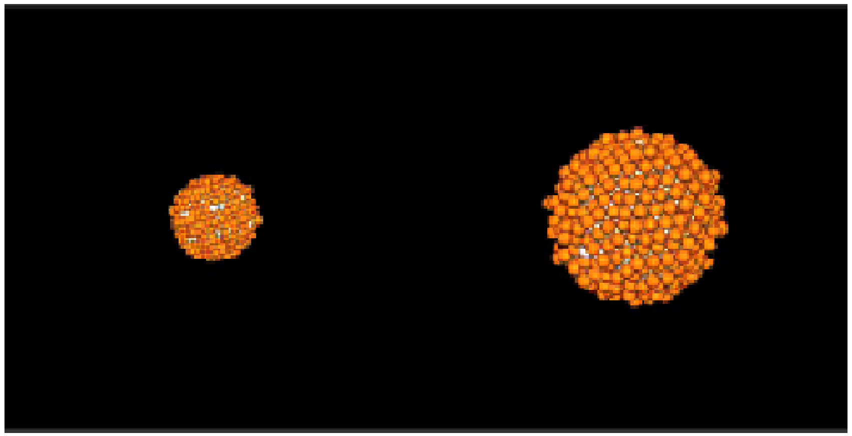
TECHNOLOGY DEMONSTRATION

ASTEROID IMPACT MITIGATION

SCIENCE







AIDA COOPERATION Asteroid Impact & Deflection Assessment

esa NASA APL The Johns Hopkins University APPLIED PHYSICS LABORATORY DLR

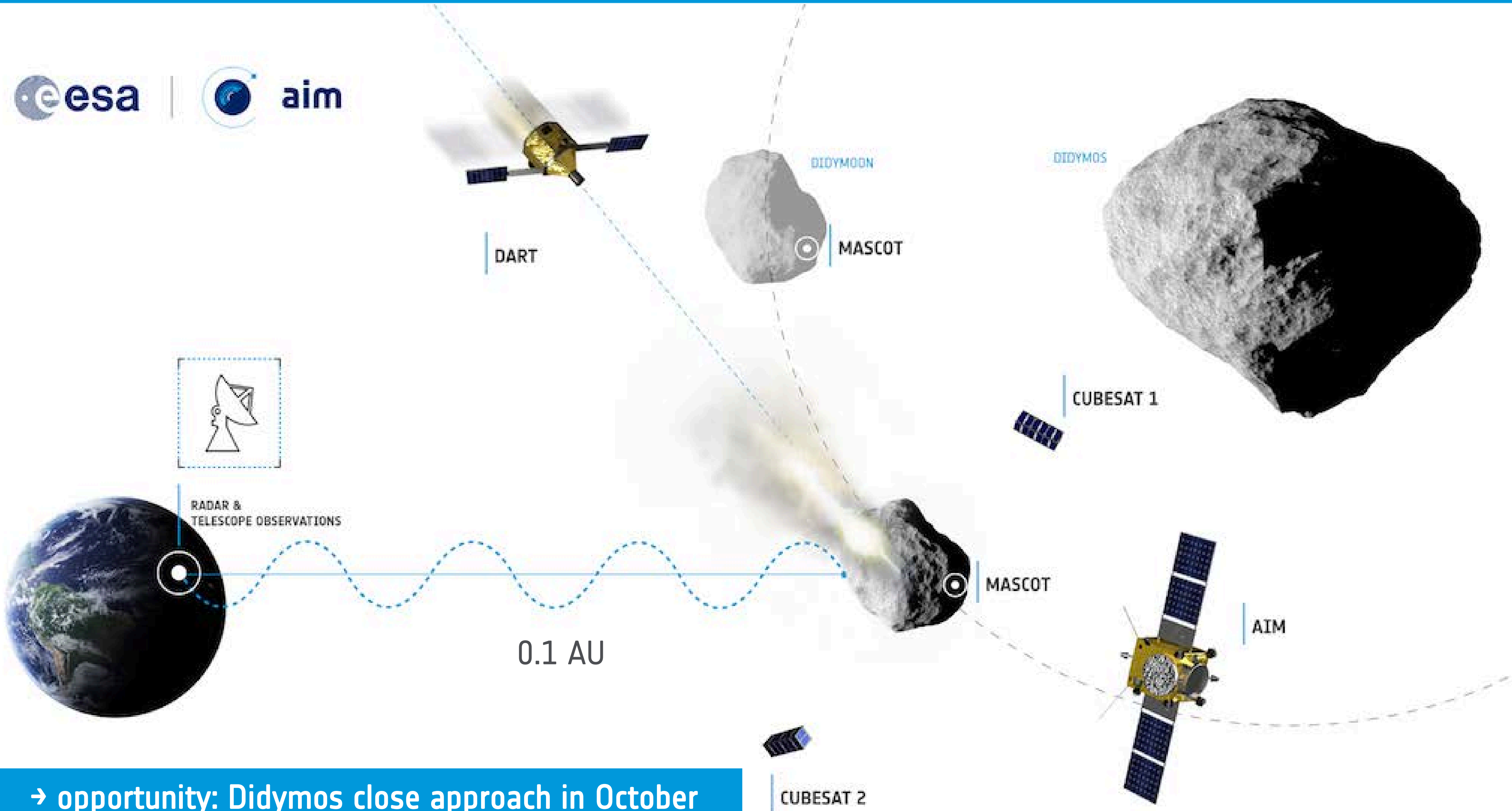
Two **simple**, **independent** and **self-standing** mission developments operated in coordination:

- demonstrate the ability to **modify the orbital path of Didymoon** and measure the deflection by monitoring the binary`s orbital period change
- measure all scientific and technical parameters to **interpret the deflection** and extrapolate results to future missions or other asteroid targets

aida

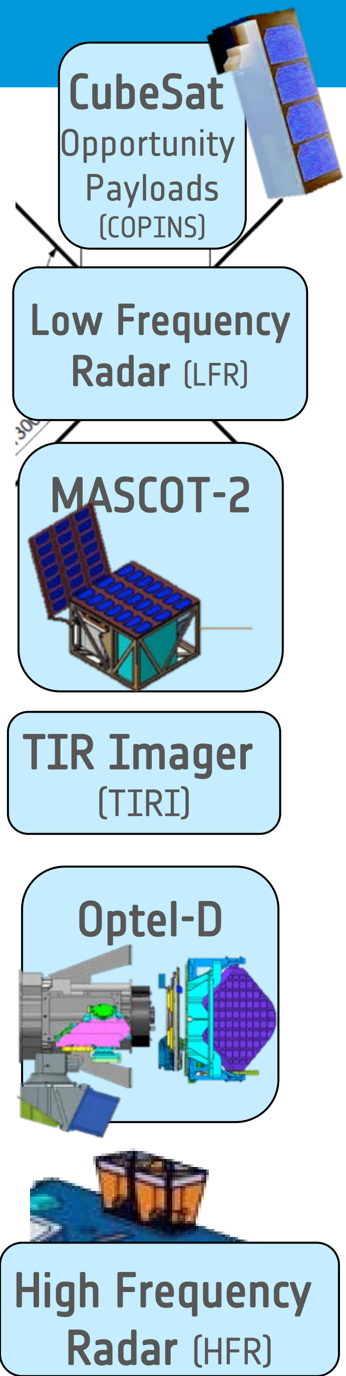
aim dart

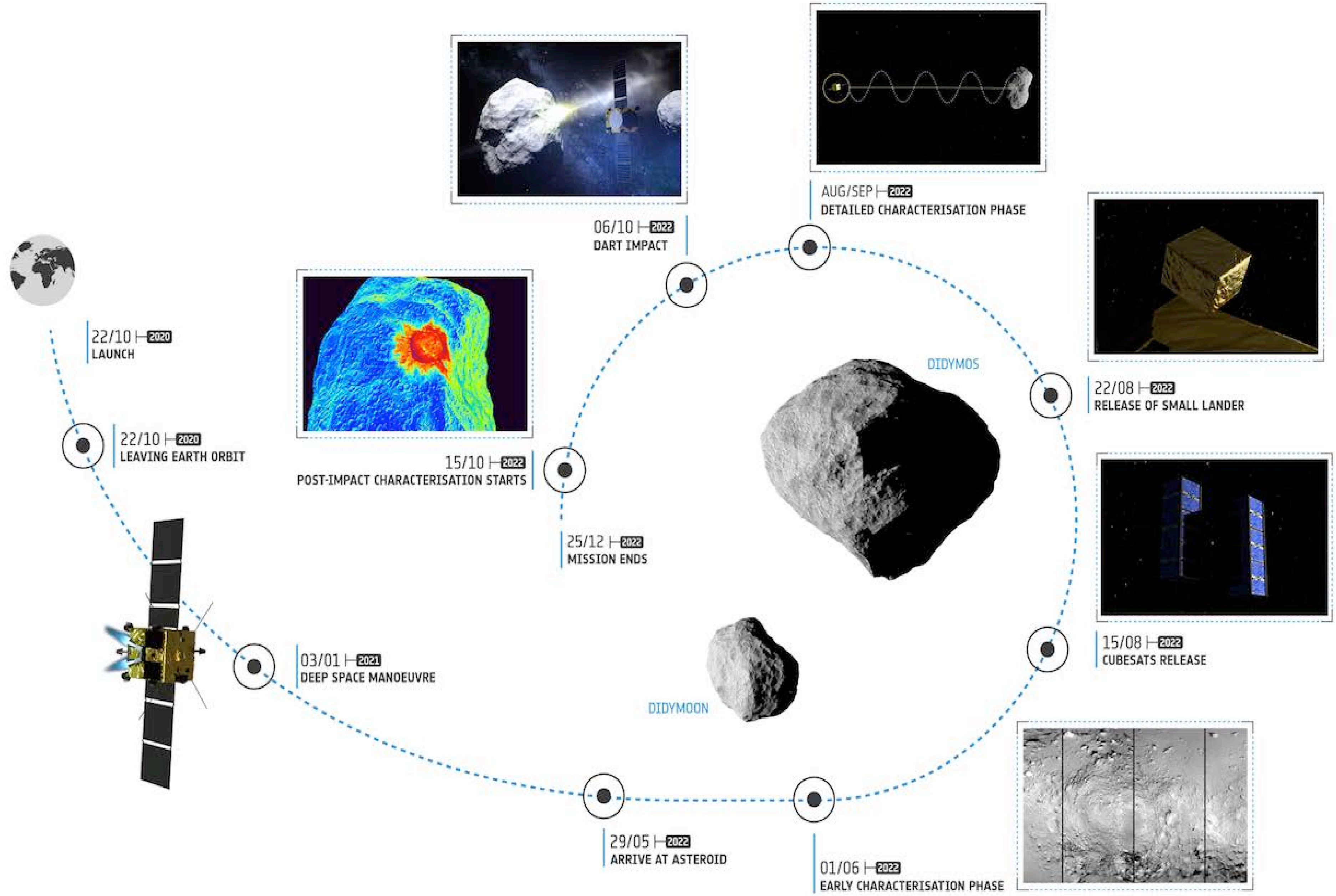
AIDA COOPERATION



→ opportunity: Didymos close approach in October 2022 asteroid, target and impact date are fixed

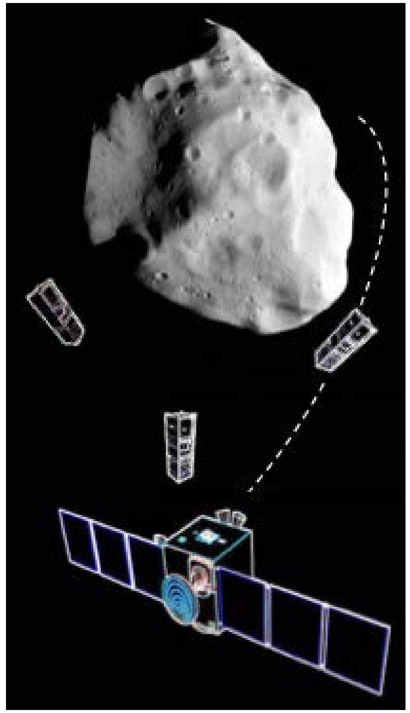
AIM PAYLOADS AND MISSION SCENARIO

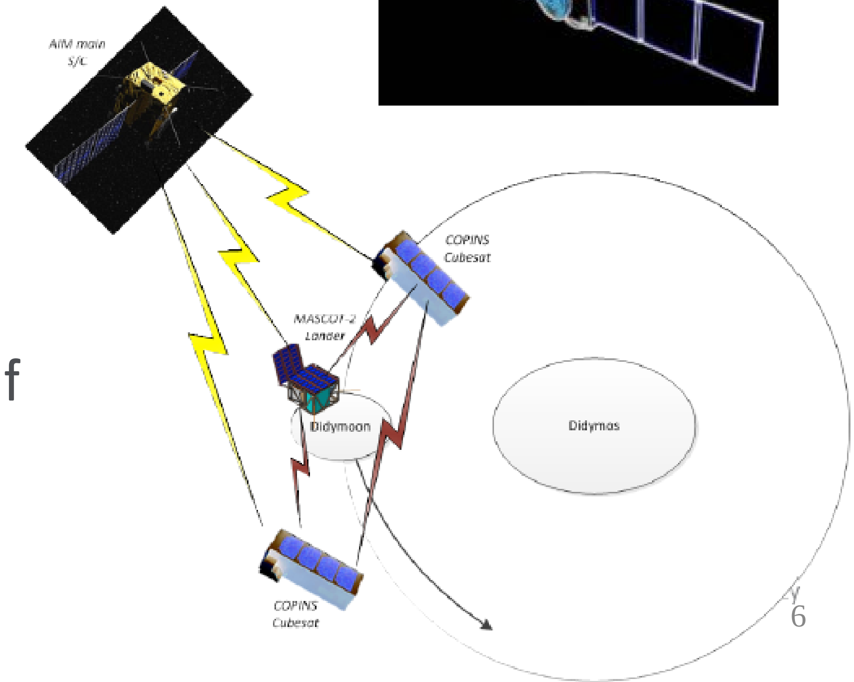




CubeSat Opportunity Payload Inter-satellite Network Sensors (COPINS)

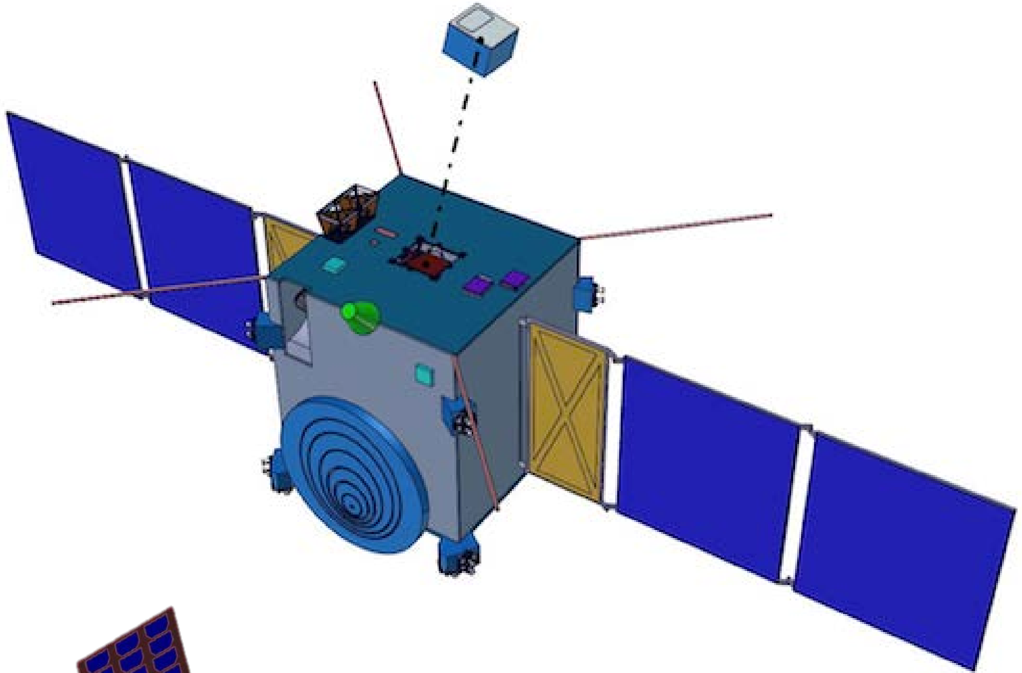
- ASPECT (1x3U): to be released at approx. 10 km altitude, then entering orbit around Didymos (4 km sma) using electric propulsion
- PALS (2x3U): to be released at 10 km or higher, then reaching stations at L4/L5, L2 and L1
- DUSTCUBE (1x3U): to be released at an altitude between 2 and 4 km, then reducing orbital radius using either cold gas or PPT
- CUBATA (2x3U): to be released at approx. 3 km altitude, then entering the same polar SSTO orbit around Didymos with 60 deg phase angle
- AGEX (2x3U): ballistic release to achieve landing of 1 cubesat and to position second cubesat to deploy 0.6 kg femtosats (chipsats)

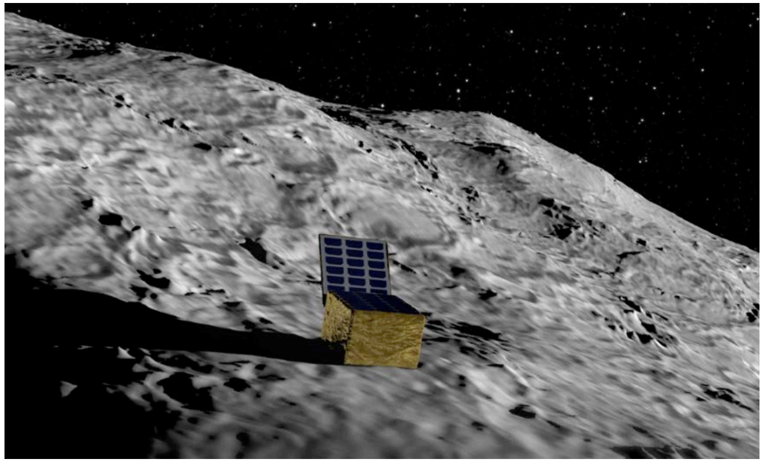


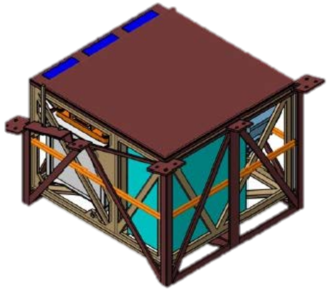


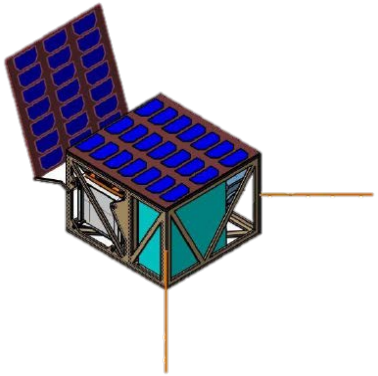
MASCOT-2 LANDER

- Size: 30 x 30 x 20 cm
- Deployable solar generator cover (supports orientation and protects solar cells during touch-down)
- 3 months operational lifetime
- Landing site: Lander targeting equatorial region of Didymoon (±60 deg latitude band)
- Carries low-frequency radar transmitter (deployable antennas)

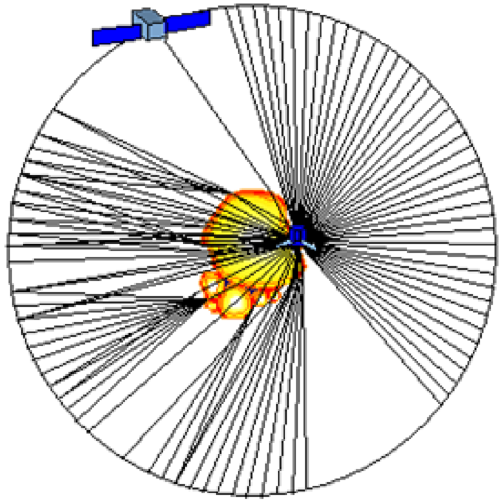






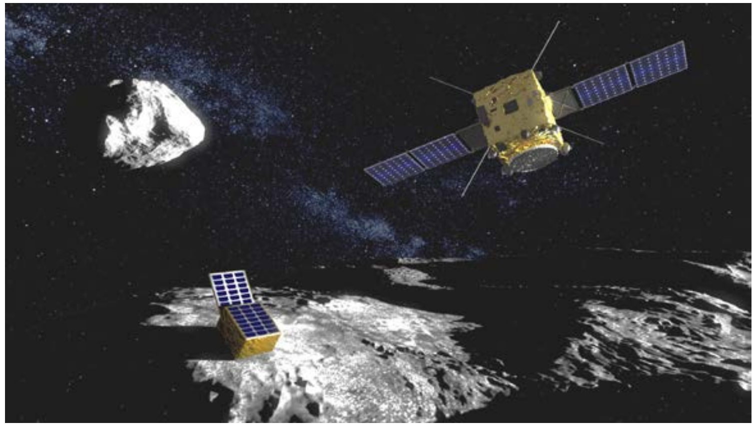


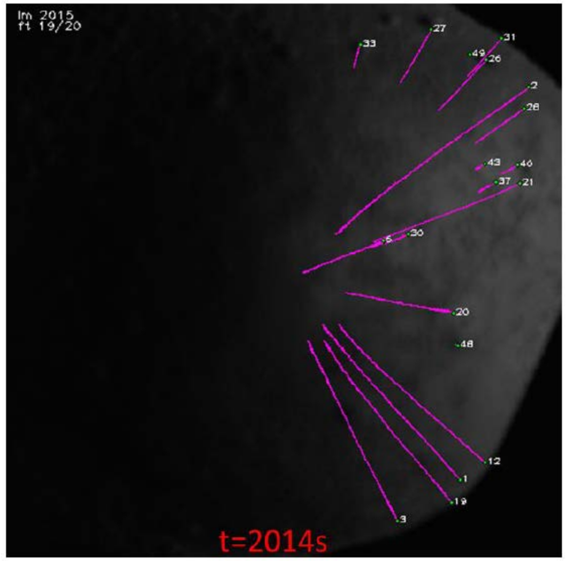
Signal to be captured by the AIM spacecraft will enable understanding the interior structure of the asteroid



OVERVIEW OF THE GNC SYSTEM FOR AIM

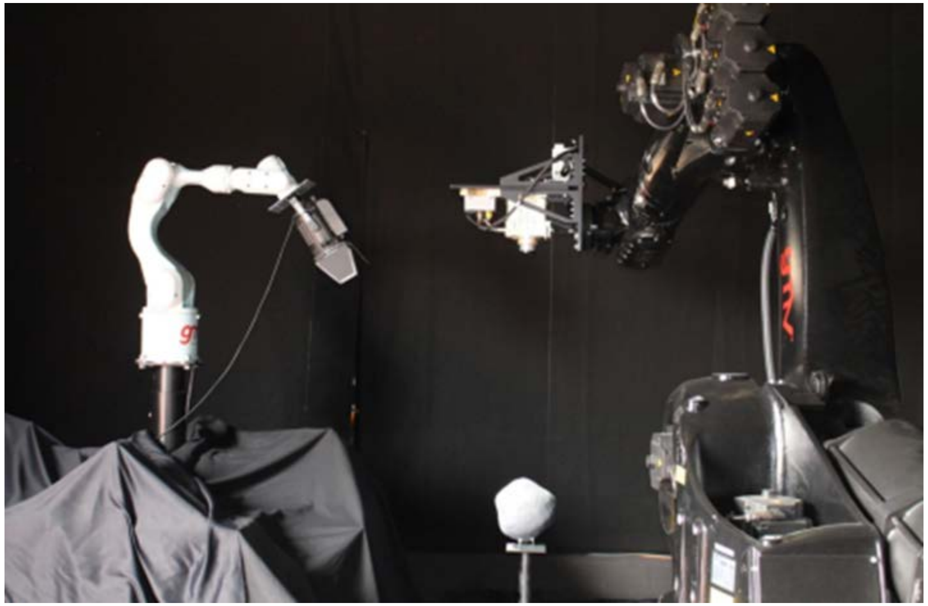
- GNC sensors and actuators are those typical of interplanetary missions that employ optical navigation:
    - Star-trackers, IMU, Sun-sensors, VIS navigation camera
    - Reaction-wheels, thrusters
- MASCOT-2 release is the most challenging phase of the mission
- Safety of the mission is critical
    - FDIR is key to guarantee safety
    - CAM capability based on VIS-only navigation means is required

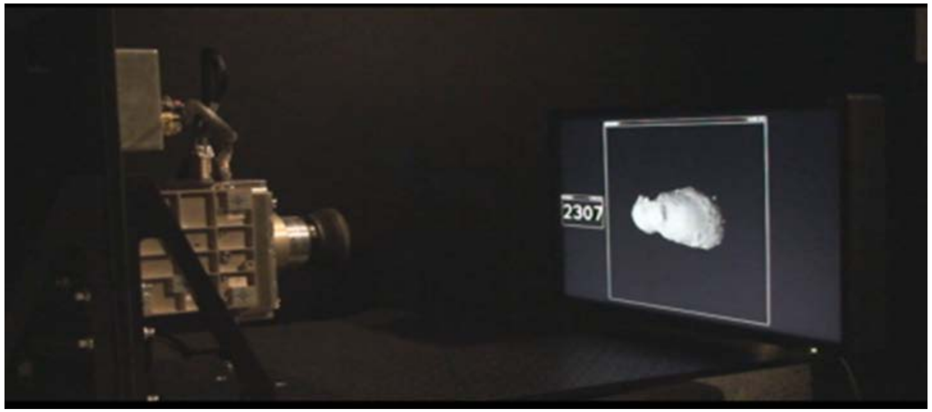




AUTONOMOUS NAVIGATION CONCEPT FOR AIM

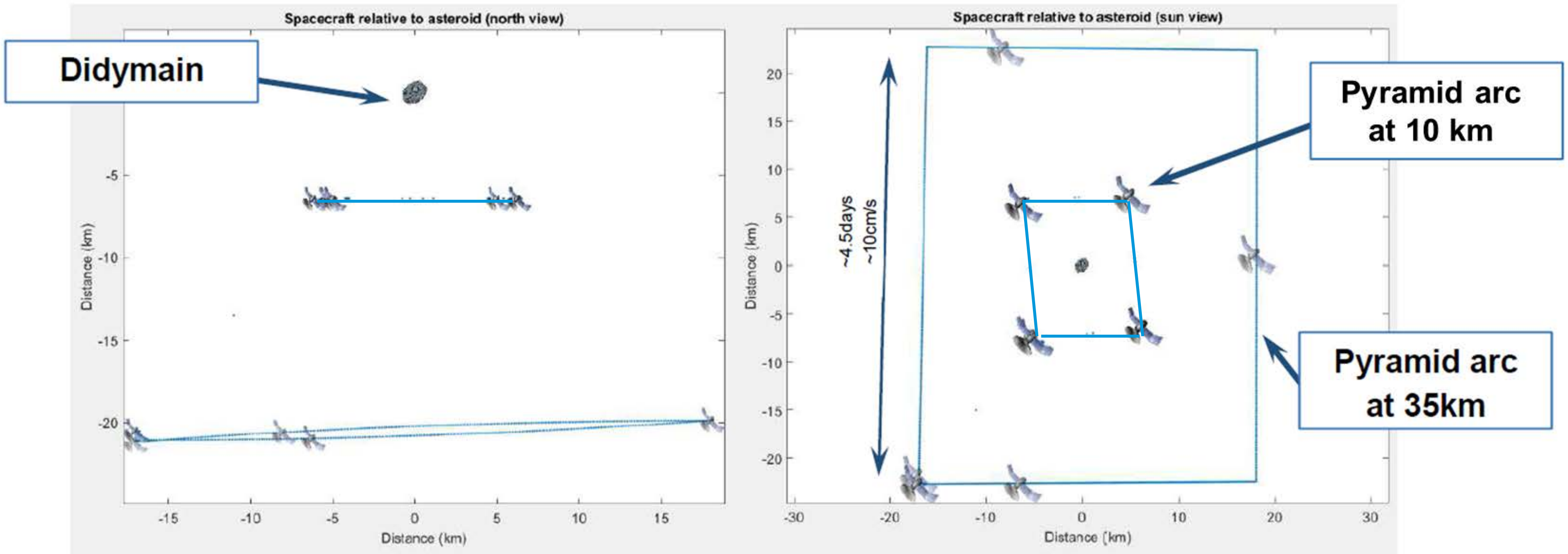
- Relative navigation is used during descent for MASCOT-2 release
- Navigation filters are initialised by ground using on-board measurments (by VIS camera, star-tracker, IMU), sent to ground and used to propagate S/C state
- Navigation is switched to autonomous mode: feature tracking used to measure change in spacecraft pose between images
- Harris corner detector for feature detection and KLT algorithm for tracking





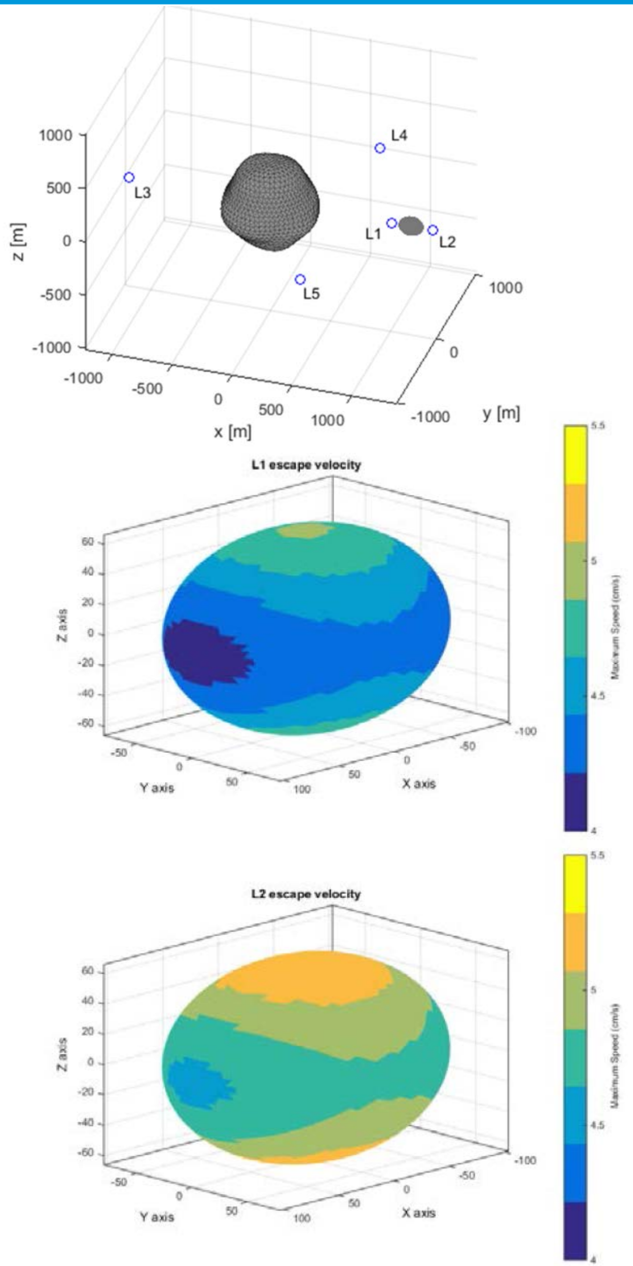
CLOSED-LOOP GUIDANCE AND TRAJECTORIES

- Closed-loop attitude guidance (based on images from VIS) is used to compensate for uncertainties in Didymos ephemeris knowledge
- Relative trajectories are defined with the primary objective to ensure safety:
  - AIM must never be on a collision course with any of the asteroids
  - Three-body dynamics exploited to maximise the chances of successful MASCOT-2 landing, while being at safe distance from Didymoon
  - Trajectories in close-proximity phase composed of hyperbolic arcs to form



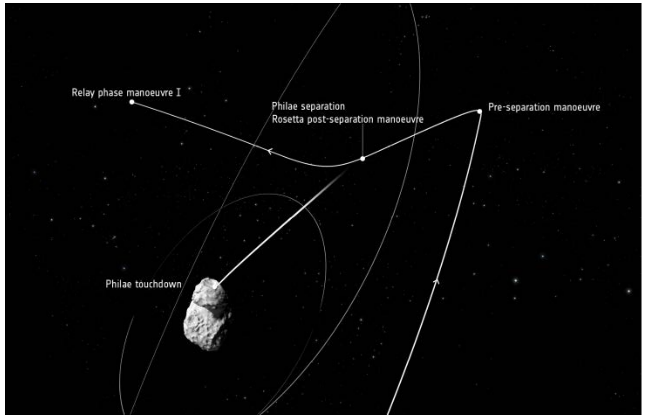
MASCOT-2 RELEASE PHASE CONSTRAINTS

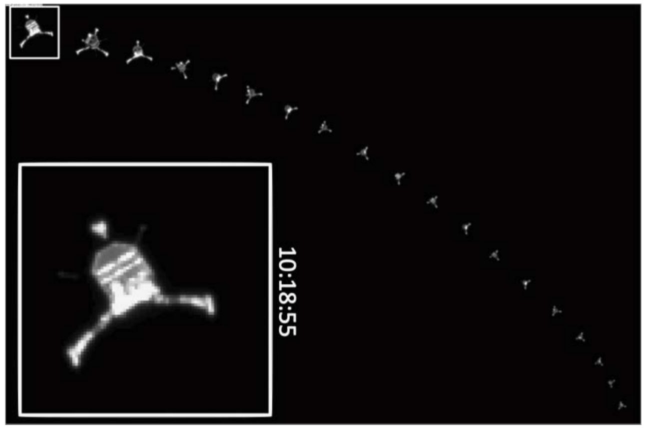
- MASCOT-2 has no means of controlling its trajectory: ballistic deployment by AIM
- The escape velocity on Didymoon is to be interpreted in the context of 3-body dynamics
  - Escape through L1 neck: 4.2 cm/s
  - Escape through L2 neck: 4.6 cm/s
- As a goal, AIM must provide radio ranging of MASCOT-2 during its descent
- As a goal, AIM must perform optical observations of MASCOT-2 during its descent



LESSONS LEARNED FROM ROSETTA/PHILAE

- Release of the lander shall not put the orbiter at risk: collision-free trajectories must be used (also passively safe, i.e. no collision in case a manoeuvre is missed)
- Assure continuous availability of optical navigation: this implies restrictions on the phase angle
- Ensure periods without maneuvers for orbit determination (typically 4/8 hours)
- Limit number of maneuvers autonomously executed



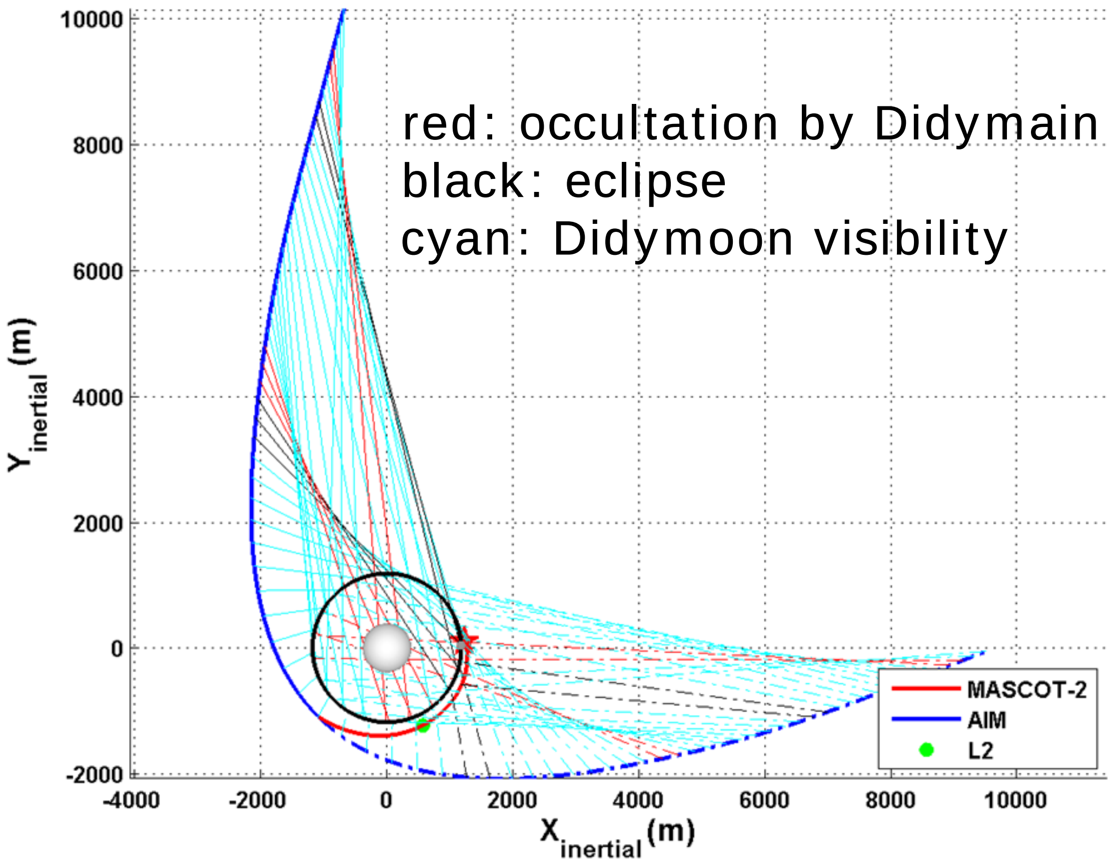


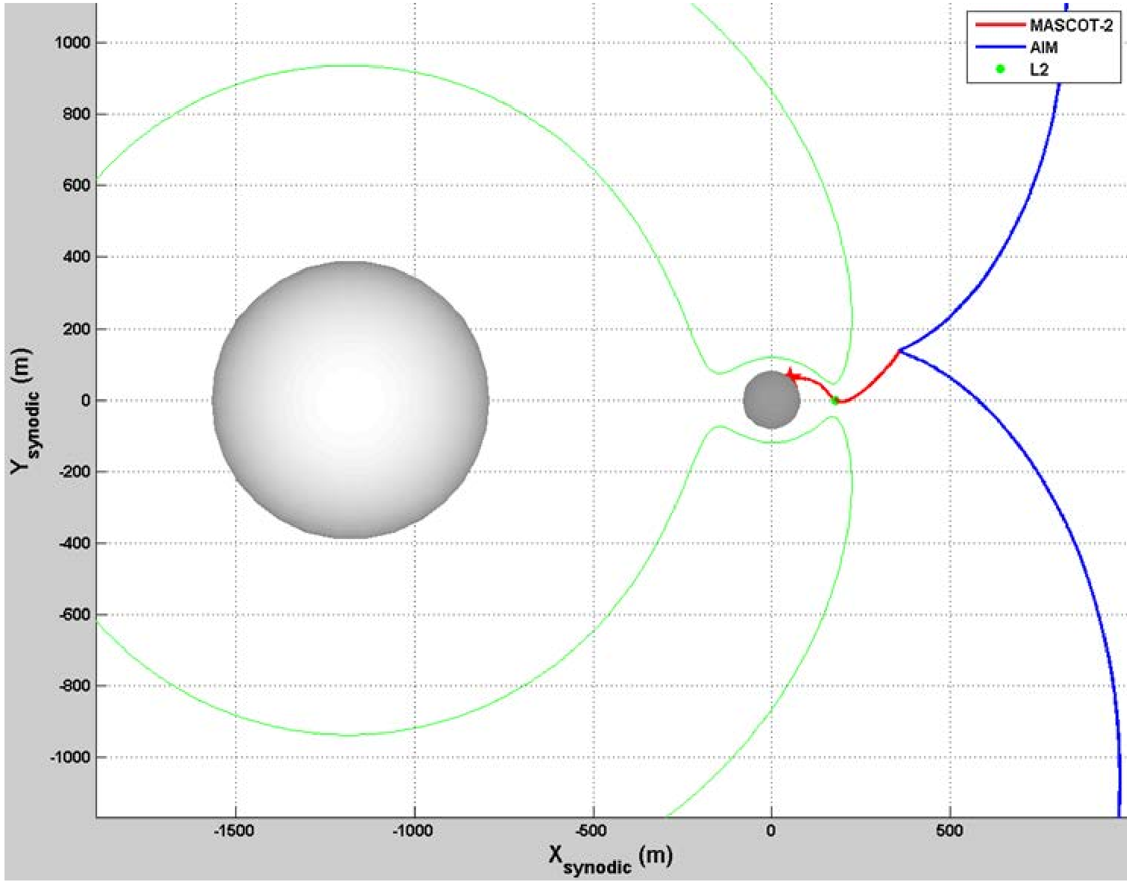
OBJECTIVES OF DESCENT TRAJECTORY DESIGN

- Minimise landing velocity by inserting MASCOT-2 in a low energy trajectory in the 3-body dynamics (through L2 neck)
- Minimise flight time while ensuring robustness to deployment position and velocity errors due to navigation and deployment mechanism (this limits the minimum velocity that can be achieved)
- Ensure observations of Didymain during the first part of the descent (low enough phase angle)
- Ensure observations of Didymoon before MASCOT-2 deployment (low enough phase angle, avoid occultation by Didymain and eclipses)
- Achieve MASCOT-2 landing immediately after eclipse with good phase angle (to ensure MASCOT-2 observability during bouncing, then power generation)
- Ensure that the angle between the release velocity and Didymoon surface is smaller than the VIS camera FOV (to allow taking images of MASCOT-2 and surface of Didymoon during deployment and descent)

MASCOT-2 DEPLOYMENT SCENARIO (1/2)

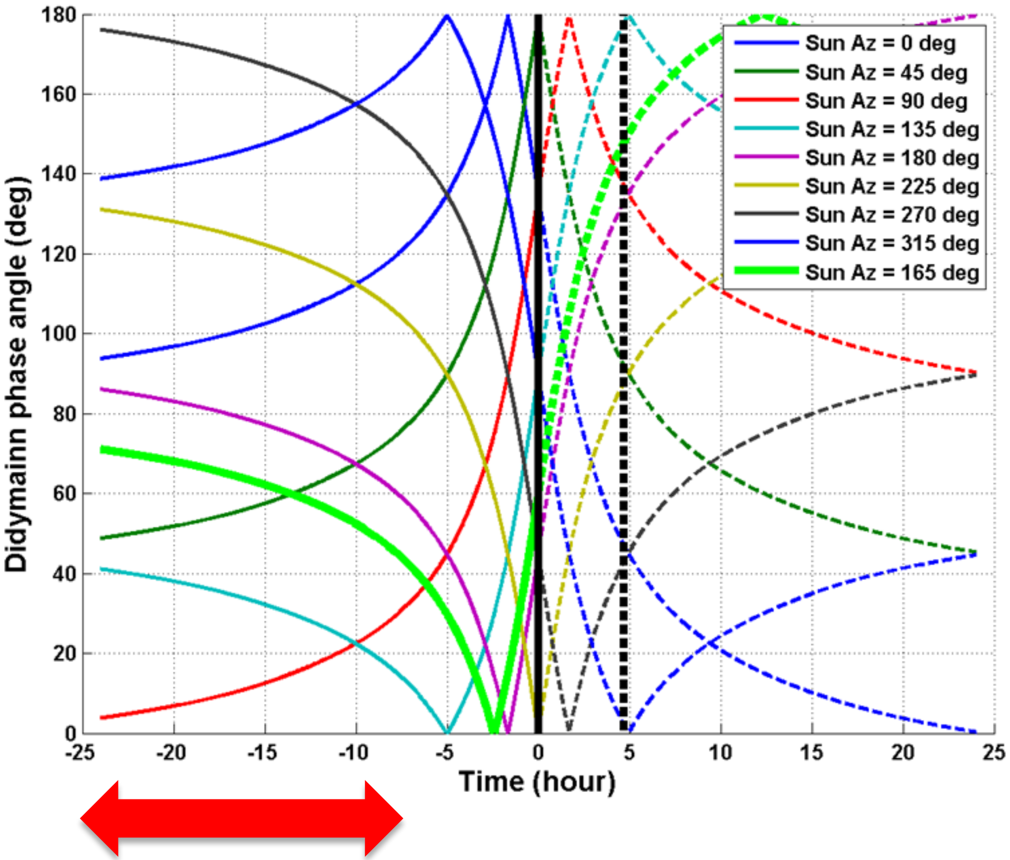
- Ensuring visibility of Didymain first, then Didymoon
- Low energy MASCOT-2 descent through L2 neck

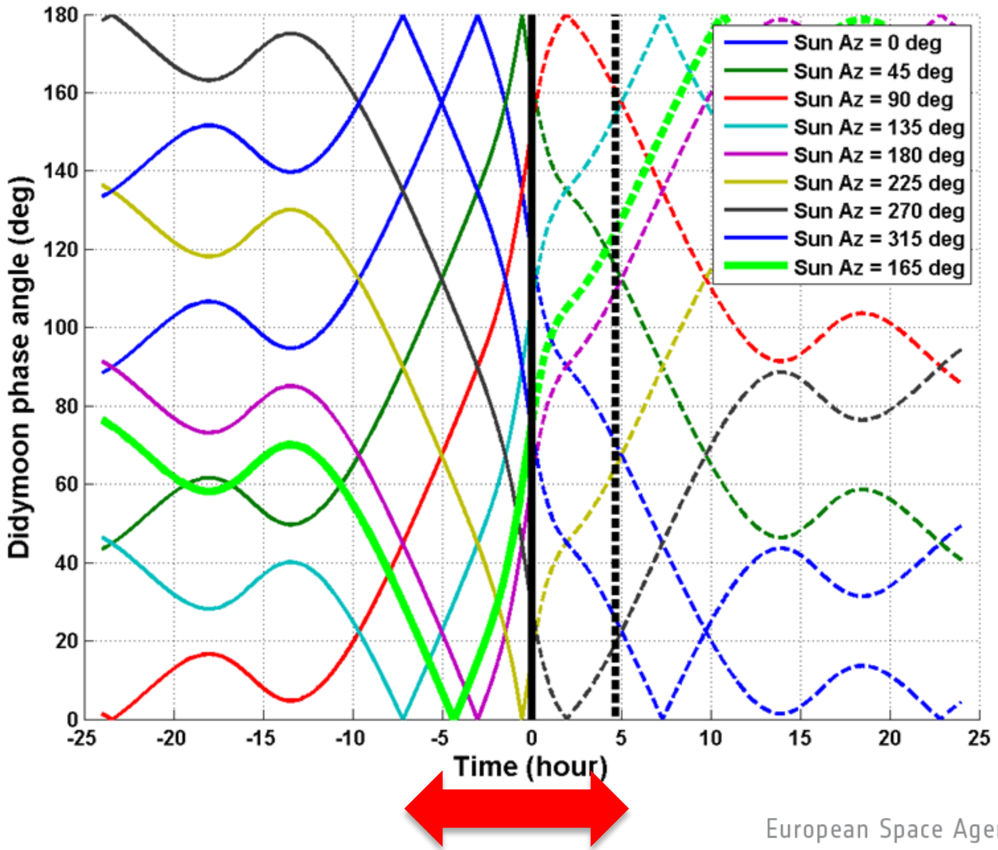




MASCOT-2 DEPLOYMENT SCENARIO (2/2)

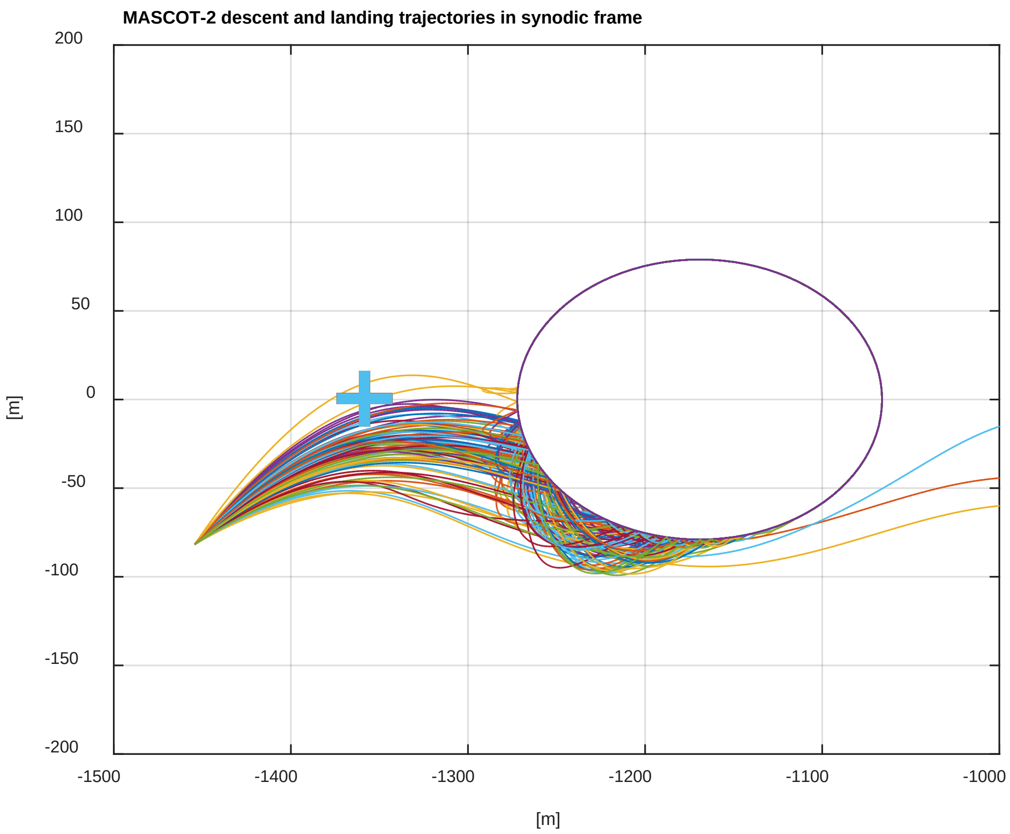
- Select phase angle to ensure proper illumination conditions for continuous optical navigation (Didymain first, then Didymoon)

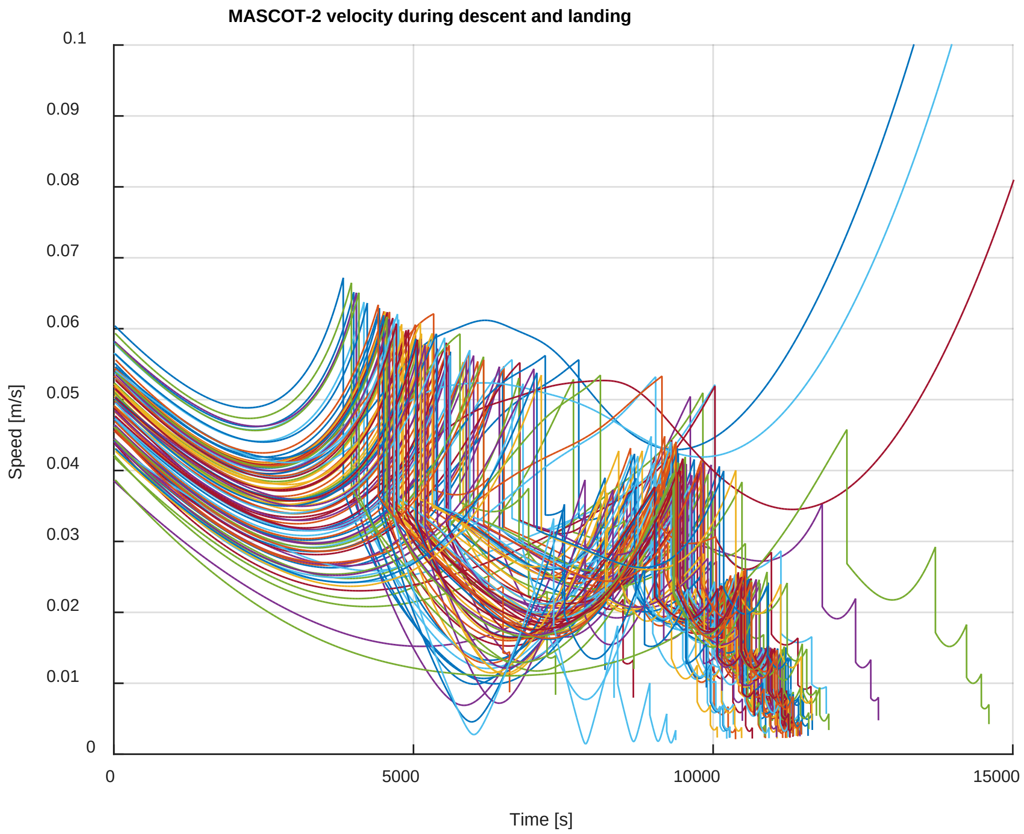




MASCOT-2 LANDING

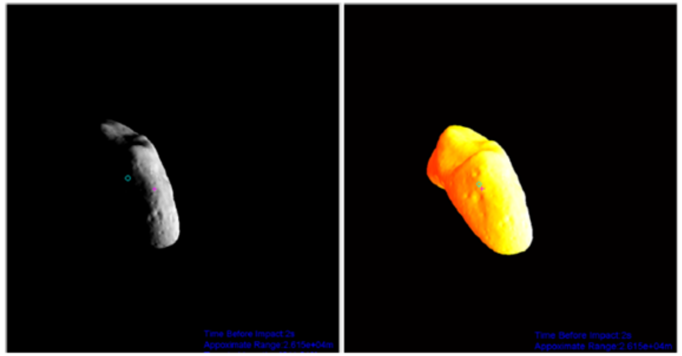
- MASCOT-2 is expected to bounce several times before coming at rest
- Relocation mechanism to hop away from unsuitable landing spots

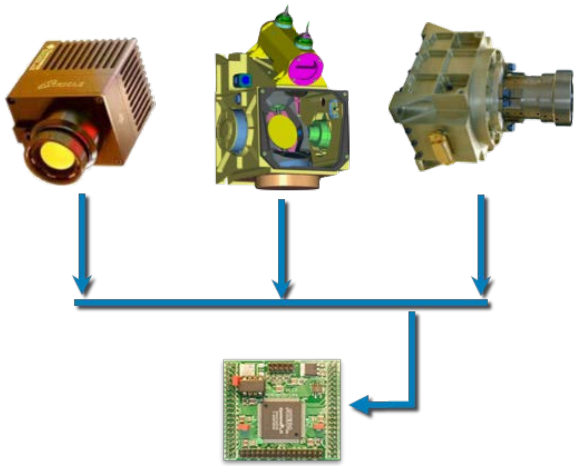


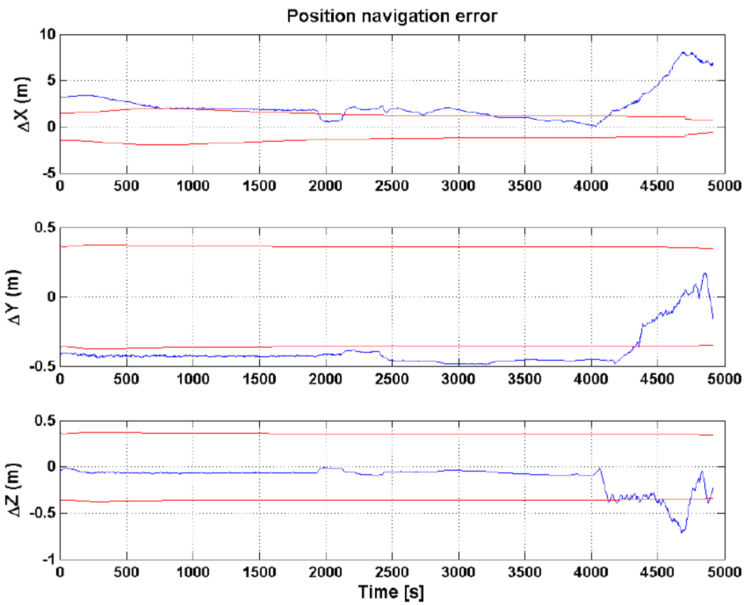


USE OF AIM SCIENTIFIC INSTRUMENTS AS GNC SENSORS: THERMAL IMAGER (TIRI), RADAR ALTIMETRY (HFR) AND LASER ALTIMETRY (OPTEL-D)

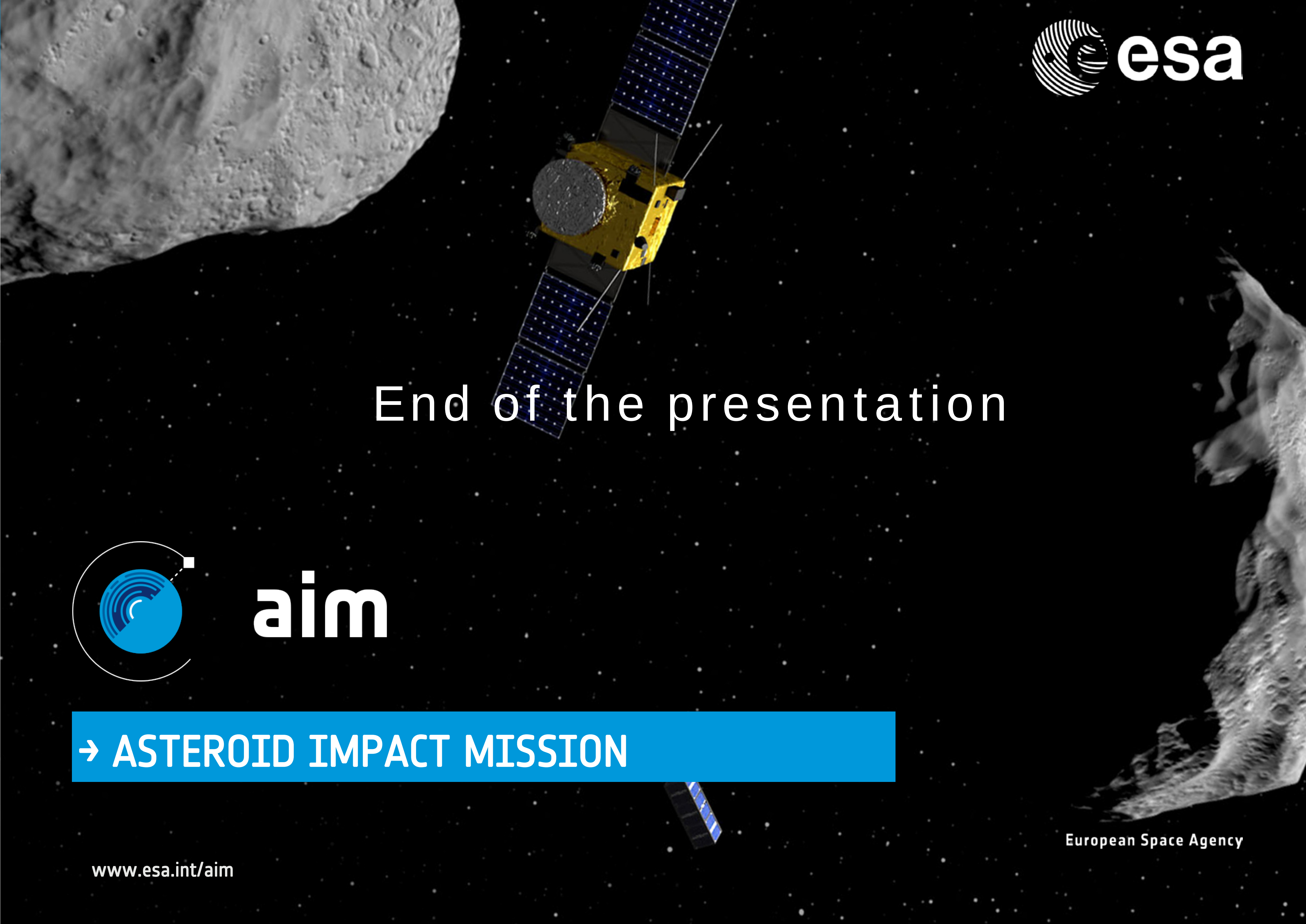
- Thermal infrared images (TIRI) to aid vision-based camera when illumination conditions are unfavorable
- Experiment to enhance navigation by use of thermal infrared images in approach phase, when distance to the asteroid is estimated based on angular size
- Altimetry (HFR/OPTEL-D) information both to augment the measurements used by ground to initialise the navigation filter and by GNC in autonomous navigation







Degradation in vertical channel due to loss of features: can be compensated by direct observability through altimeter


esa
End of the presentation
aim
→ ASTEROID IMPACT MISSION
European Space Agency
www.esa.int/aim

Back-up slides

AIM MISSON OBJECTIVES

Demonstrate the ability to **modify the orbital path of Didymoon** and measure the deflection by monitoring the binary`s orbital period change

- Measure all scientific and technical parameters to **interpret the deflection** and extrapolate results to future missions or other asteroid targets
- Correlate ground-based observations with in-situ measurements

Demonstrate technologies for future deep-space missions:

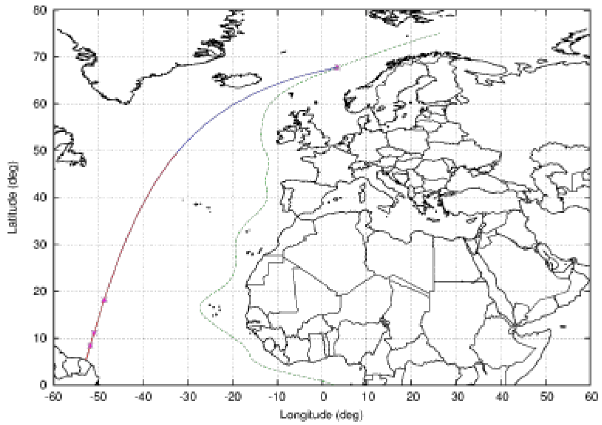
- **Interplanetary optical communication**
- **Deep-space inter-satellite links**
- **µ-lander deployment in deep-space**

Answer fundamental questions on our Solar system:

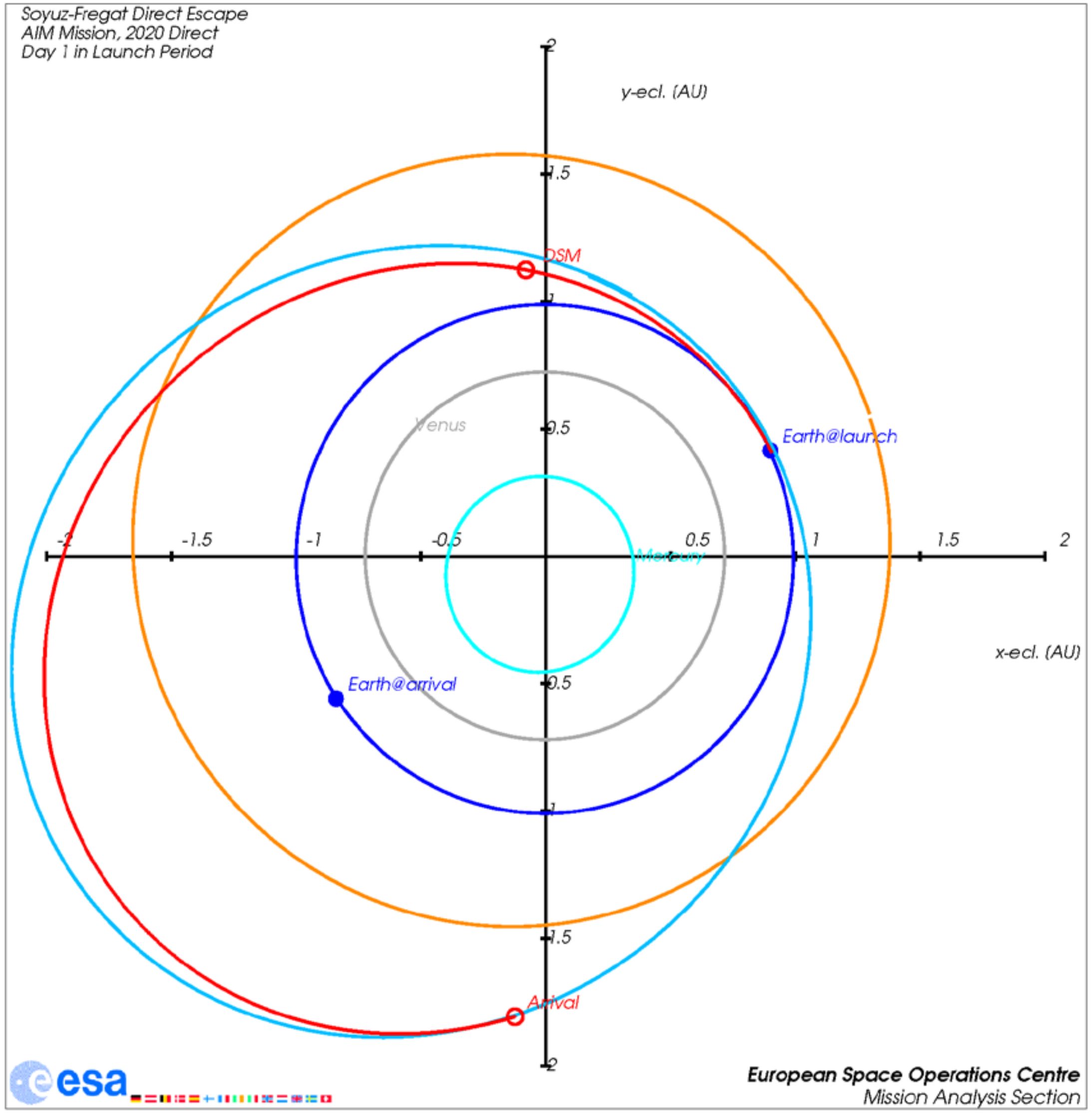
- are the **collisional models** describing formation and evolution of the Solar System valid?
- what physical processes lie behind the **formation of binary asteroids**?
- what is the **internal and subsurface structure of the natural satellite** of a binary NEA?
- what **links** can be established **between subsurface and the surface properties**?
- what are the **mechanical properties** of a small asteroid's **surface**?
- what **cohesion is there inside an aggregate in microgravity**?

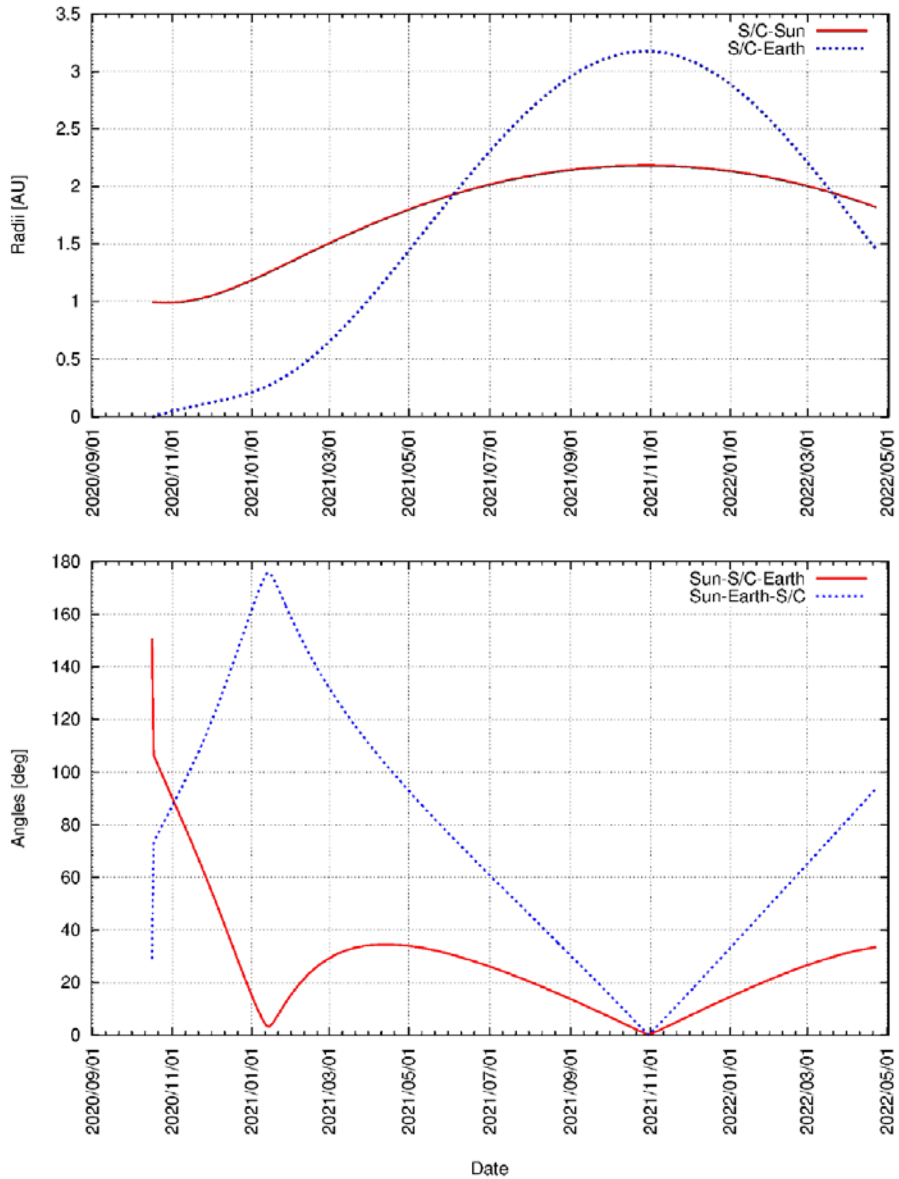
AIM LAUNCH SCENARIO

Day in Launch window	1	6	11	16	21
Liftoff Date	**2020/10/17**	**2020/10/22**	**2020/10/27**	**2020/11/1**	**2020/11/6**
Escape vel. [km/s]	5.191	5.042	4.994	5.034	5.154
Escape R.A. [deg]	136.5	132.6	128.3	124.3	120.9
Escape dec. [deg]	22.8	24.3	25.9	27.4	28.9
DSM date	2020/12/20	2020/12/16	2020/12/20	2020/12/25	2020/12/29
DSM size [m/s]	**95**	**97**	**118**	**159**	**227**
SAA [deg]	101.0	104.8	113.5	124.9	138.0
Sun distance [AU]	1.13	1.11	1.12	1.14	1.15
EAA [deg]	127.9	133.8	134.6	139.2	147.2
Earth distance [AU]	0.17	0.15	0.15	0.16	0.17
Idealized Arrival			**2022/4/24**		
Insertion [m/s]	1155	1153	1132	1091	1022
		Total Δv [m/s]			**1250**
Transfer duration [d]	**554**	**549**	**544**	**539**	**534**



INTERPLANETARY TRANSFER

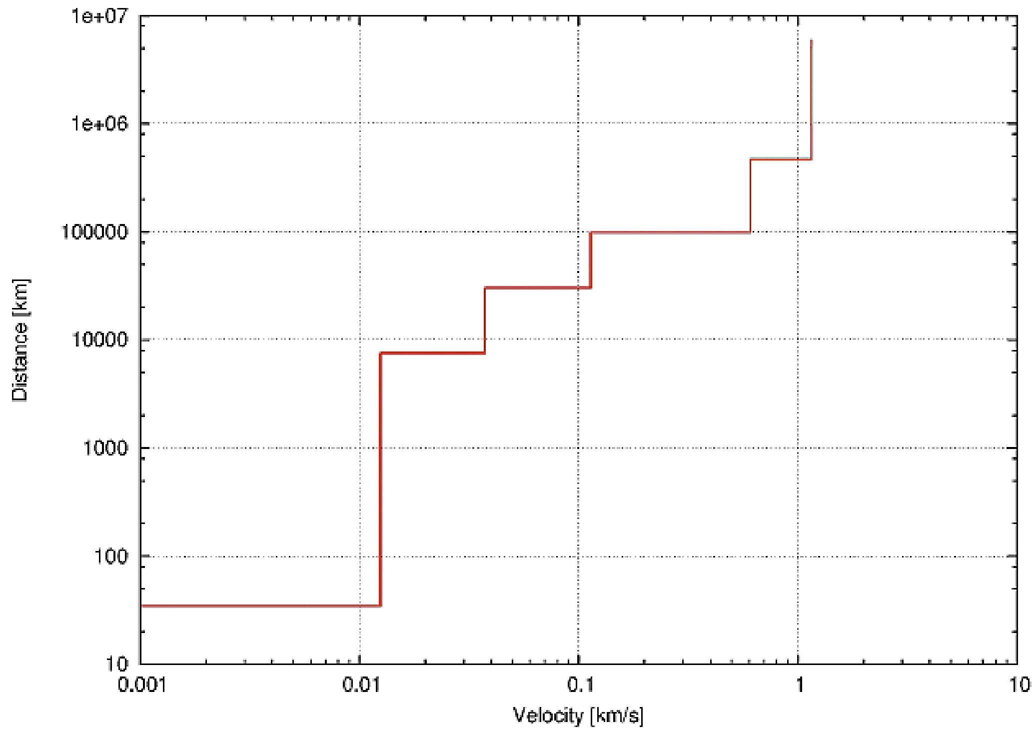




ency

DIDYMOS ARRIVAL

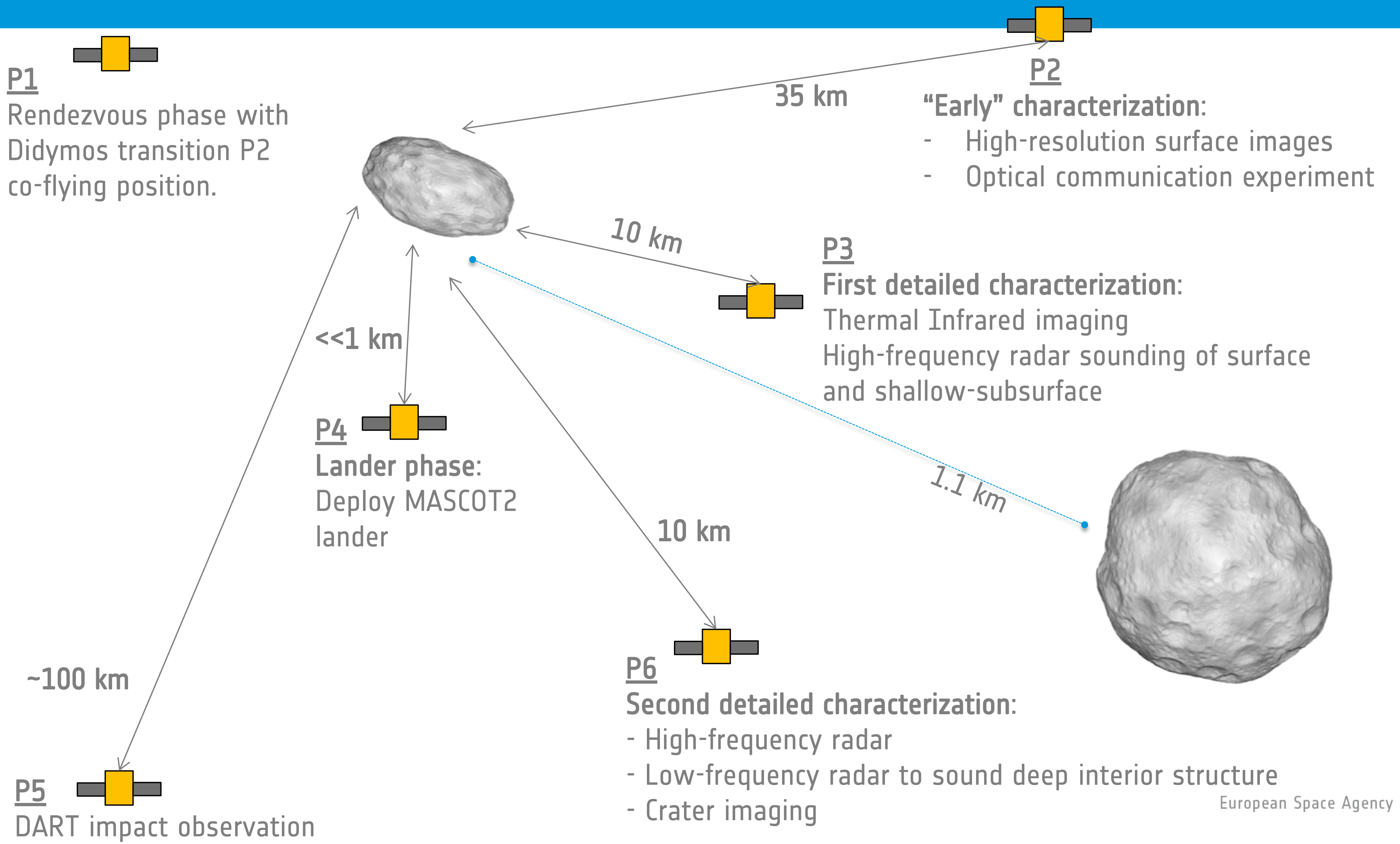
Case	LPO	LPC
Manoeuvre 1 date	2022/4/19	2022/4/15
Manoeuvre 1 size [m/s]	546	338
Manoeuvre 2 date:	2022/4/26	2022/4/22
Manoeuvre 2 size [m/s]	496	306
Manoeuvre 3 date:	2022/5/3	2022/4/29
Manoeuvre 3 size [m/s]	76	204
Manoeuvre 4 date:	2022/5/10	2022/5/6
Manoeuvre 4 size [m/s]	25	117
Manoeuvre 5 date:	2022/5/17	2022/5/13
Manoeuvre 5 size [m/s]	13	58
Total Δv [m/s]	1155	1023



Manoeuvre #	Date	Distance [km]	Approximate ast. brightness
1	2022/4/19	5.3E5	+8.5mag
2	2022/4/26	1.2E5	+5.2mag
3	2022/5/3	3.4E4	+2.5mag
4	2022/5/10	9E3	-0.5mag
5	2022/5/17	35	

CLOSE PROXIMITY ASTEROID OPERATIONS

29 May 2022 – 25 December 2022



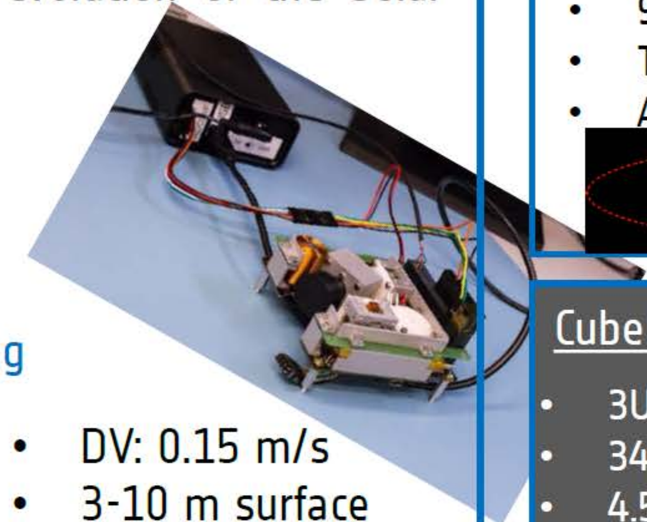
European Space Agency

COPINS concept 1: VTT (near-IR spectral measurement, 1x3U)

Asteroid Spectral Imaging (ASPECT) Mission Concept

"Composition of the Didymos asteroid and the effects of space weathering and shock metamorphism in order to gain understanding of the formation and evolution of the Solar System."

- Measure of reflectance spectra
- Space Weathering
- Shock experiment
- Plume Observations
- Spectral observations *and* modelling



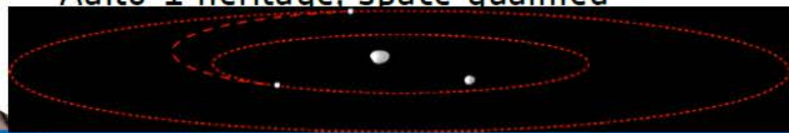
- DV: 0.15 m/s
- 3-10 m surface resolution goal

The network of molten metal and sulfide veins in the dark-colored lithology acts as the darkening agent (Kohout et al. 2014).

Proposed Payloads

Asteroid Spectral Imager.

- 500-950 nm, 950-1600 nm, 1600-2500nm, FoV 5^0
- 97 x 97 x 97 mm, 900g, 7 W
- TRL 6-7even!
- Aalto-1 heritage, space qualified



CubeSat Mission Design

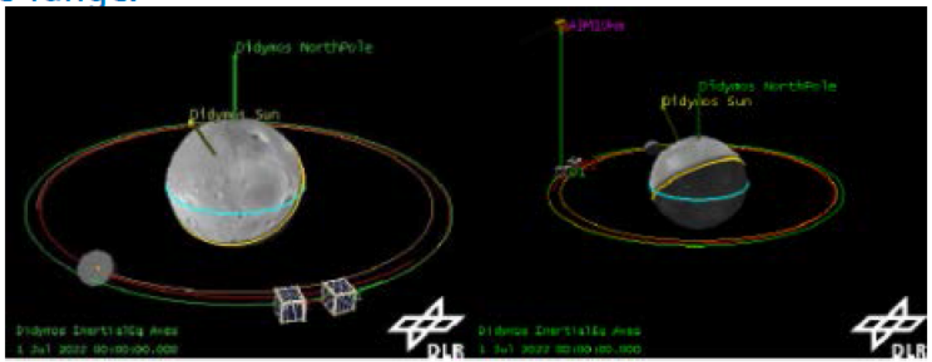
- 3U CubeSat
- 340 x 100 x 100 mm
- 4.5 kg, 10 W gen.
- < 1^0 Pointing accuracy
- Aalto 1&2 heritage
- AOCS enhancements for pointing
- 10 km alt. deployment, orbit around binary

COPINS concept 2: Swedish Institute of Space Physics (magnetometer, volatiles, camera, 2x3U)

PALS Mission Concept

"The CubeSats will characterise the magnetization, the main bulk chemical composition and presence of volatiles as well as do super-resolution surface imaging of the Didymos components impact ejecta."

- Characterize the magnetization of primary and secondary.
- Investigate the composition of volatiles around primary and secondary.
- Investigate the composition of volatiles released from the DART impact site.
- Super-resolution surface imaging from close range
- Investigate the DART collision and plume development at close range.



Proposed Payloads

Fluxgate Magnetometer (TRL 5)
- 0.8 kg, 0.5 W, 100x80x100 mm

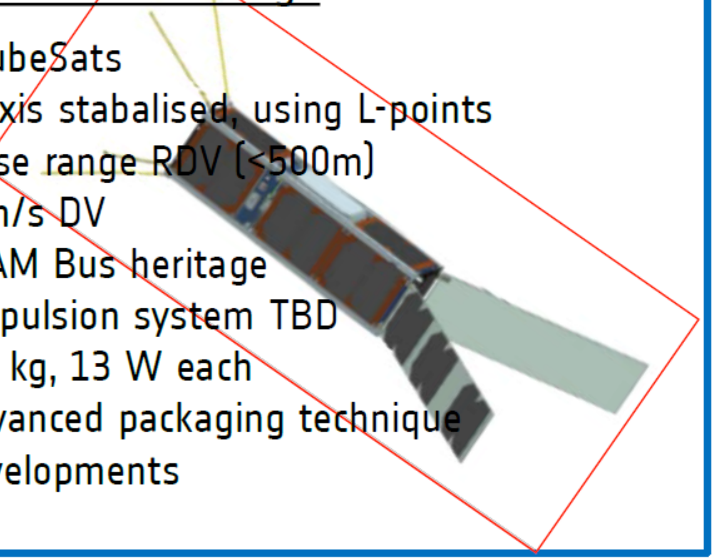
Volatile Composition Analyser (TRL 4)
- 0.8 kg, 2 W, 132x100x74 mm

Narrow Angle Camera (TRL 5-7)
- 0.4 kg, 2.5W, 120x100x100 mm, 50^0 FoV

Video Emission Spectrometer (TRL 5-7)
- 0.4 kg, 2.5W, 120x100x100 mm

CubeSat Mission Design

2 3U CubeSats
- 3-axis stabalised, using L-points
- Close range RDV (<500m)
- 7 m/s DV
- SEAM Bus heritage
- Propulsion system TBD
- 5.4 kg, 13 W each
- Advanced packaging technique developments

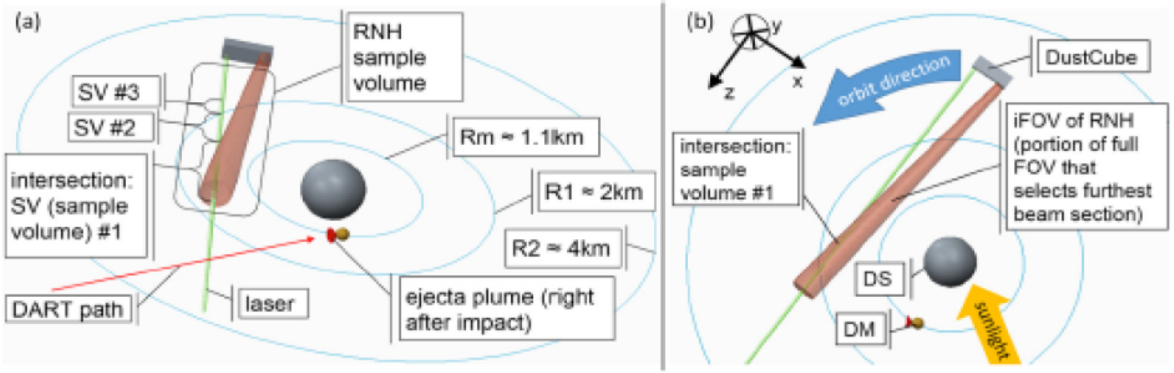


COPINS concept 3: University of Vigo (nephelometer, 1x3U)

DustCube Mission Concept

"Complementing the sensing capabilities of AIM, to better characterize the ejected dust plume after impact. Over a full scattering angle range, retrieval of size, shape, and refractive index of the grains."

- Size, shape, refractive index and concentrations of ejected dust
- Constrain mineralogical composition
- Compliment the demonstration of the end to end optical communications system TEX
- Aid the study of interplanetary dust evolution.
- Measure the BRDF of the asteroid surface



Proposed Payloads

In-situ Nephelometer (TRL2/3)

- Heritage from PI-Neph
- 2 W,
- 15^0 AKE

Remote Nephelometer (TRL 3)

- 2^0 FoV, 500x500 pixels
- 0.003^0 angular resolution

CubeSat Mission Design

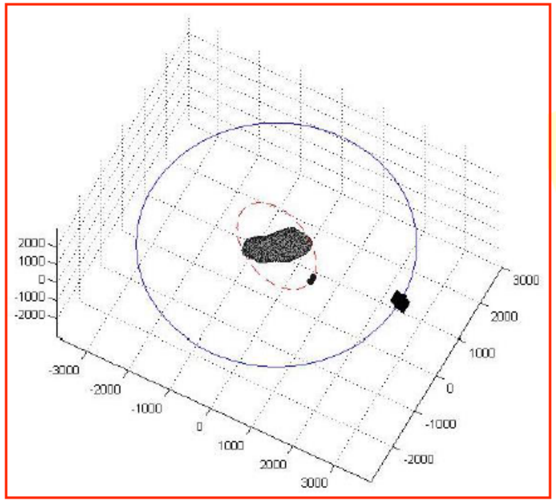
- 3U CubeSat
- Xatcobeo and HumsatD heritage
- Cold gas or PPT for 1m/s DV
- 4 Non-deployable solar panels
- Addition of new AOCS system (Un. Bologna)
- 4.5 kg, 5 W generation
- Deployed by AIM between 2- 4km, with options for spin stabalisation

COPINS concept 4: GMV (radioscience, imaging, seismology, 2x3U)

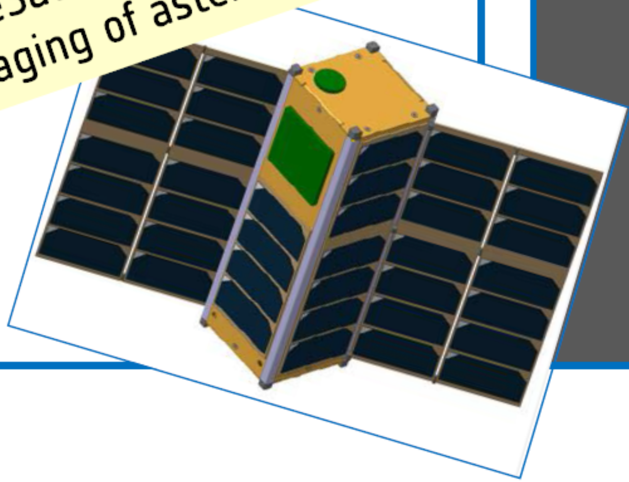
CUBATA Mission Concept

"Measurement of the gravity field of the Didymos system before and after the impact and the observation of the DART impact."

- Determine the gravity field of the Didymos system before and after the impact.
- Observe the impact from DART from a short range and its effects
- Perform seismology during the impact
- Determine the velocity field of the ejecta



- Doppler tracking of CubeSats using AIM
- Imaging of asteroids



Proposed Payloads

Camera Payload (TRL TBD)

- FoV 15^0, 320g,
- 1 m resolution at 3 km, 10 fps
- OPTOS CubeSat heritage

Transponder ESA CFI or other (TRL 3-6)

- S-Band, 216g
- Frequency turn around
- Ultra-stable oscillator development

CubeSat Mission Design

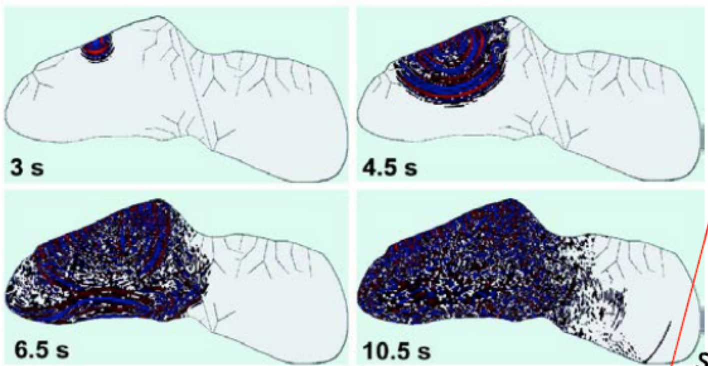
- 2 x 3U CubeSats
- One could land. Deployed approx. 3 km using typical; CubeSat approach.
- 3.6 m/s DV, propulsion system
- 3-axis stabalised
- 1 deg APE
- 6.5W-14.2W
- 4.5 kg
- 125.2 Mbits data generation

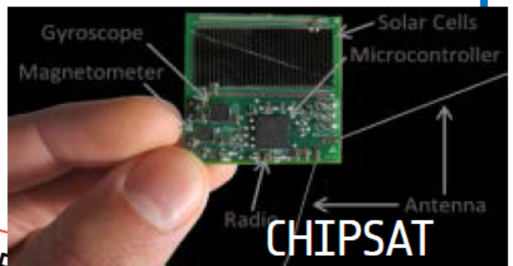
COPINS concept 5: Royal Observatory of Belgium (Seismometer, cameras, gravimeter + chips, 2x3U)

Asteroid Geophysical Explorer (AGEX) Mission Concept

"Determination of dynamical state, geophysical surface properties, subsurface structure and the assessment of the DART impact on the asteroid dynamic properties."

- Characterise the mechanical properties of the surface material
- Characterise the average seismic properties of the sub-surface (<10m) thus providing constraints on the properties of the sub-surface
- To determine, the rotational kinematics prior to the DART impact
- Determine surface gravity and thus providing constraint on the mass and density
- Determine global scale accelerations and surface motions associated with the DART impact





Properties of Seismic Waves. Shown here are examples of propagation as a function of time to investigate the internal structure.

Proposed Payloads

Three seismometer
- Commercial geophones <400g, 0.3 W
- To be space qualified, TRL 3/4

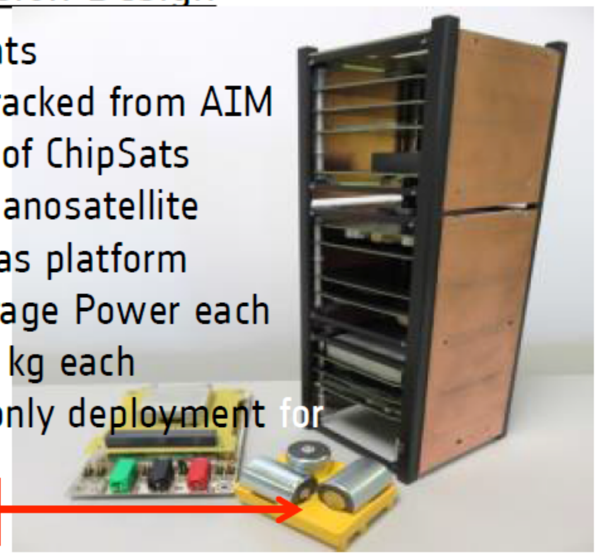
Accelerometers (TRL 6)
- 48g, 0.65 W, 47 x 44 x 14 mm.

Gravimeter (optional alternative) (TRL 2)
- 120g, 0.25 W, 8 x 8 x 50 mm
- To be space qualified TRL 3-4

0.6 kg of femto spacecraft

CubeSat Mission Design

2 3U CubseSats
- Lander, tracked from AIM
- Deployer of ChipSats
- NAOSat nanosatellite selected as platform
- 6 W Average Power each
- Around 3 kg each
- Ballistic only deployment for landing



Seismometer