DEFENCE AND SPACE

NEO-MAPP µLander: Safe and Autonomous Landing in Unexplored Asteroid Environment

Robotic Exploration

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Agenda

1. NEO-MAPP Project
2. GNC System Drivers
3. Concept of Operations
4. GNC Design
5. Navigation and Autonomy

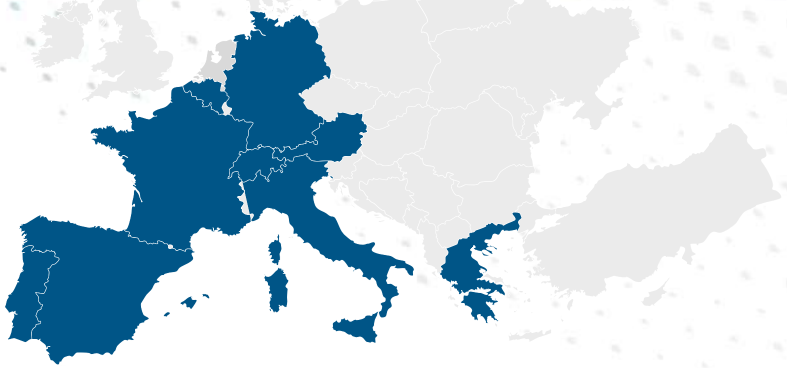
Keywords: asteroid landing, trajectory optimization, autonomous landing site selection, HDA, VBN, machine learning, meta-heuristic methods, computer vision

NEO-MAPP Scenario

NEO-MAPP Scenario

Near **E**arth **O**bject **M**odelling **a**nd **P**ayloads for **P**rotection

- The NEO-MAPP study is funded by the **European Commission's Horizon 2020** (End date June 2023).
- More than 15 **European partners** collaborate to the project



Philae lander

- AIRBUS responsibility is to **develop** and **verify** robust **GN&C** strategies and **technologies** enabling surface interaction and direct response measurements performed by a µLander architecture.

→ Define a **µLander** architecture followed by algorithm development and verification

NEO-MAPP Scenario | µLander Technologies

Payload (developed by NEO-MAPP partners in collaboration with Hera mission)**:**

- Bistatic radar (Grenoble University)
- Gravimeter (Royal Observatory of Belgium)
- Seismometer (ISAE-Supaero)

Reference Scenario:

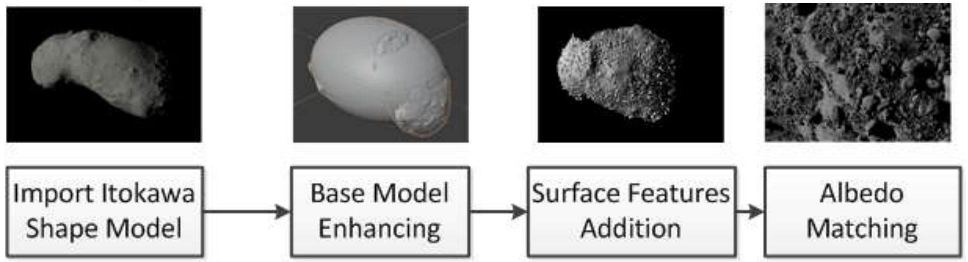
- Didymos system binary environment (**DART/Hera**)
  - Target: Landing on secondary body (Dimorphos)

Modelling:

- NASA Ephemerides for orbital information
- Enhanced shape model for Didymos and Dimorphos

PANGU Synthetic Didymos Environment

DART Camera Stream from **last night**



Modelling workflow

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GNC System Drivers

System Drivers

Objective:

Autonomous and Safe Landing of a µLander in a partially known environment from a 5 km orbit.

System Driver	Impact on GN&C	GN&C Functionalities
Environment	Limited knowledge Lack of a-priori landing map	Robust algorithms Physical parameter estimation
Reduced impact of GN&C on the S/C (Mobility backpack)	Uncoupled avionics from payloads Light and simple architecture	COTS avionics Strongly mass-optimized GN&C
Autonomy	Autonomous decision making No absolute navigation solution	Safe landing site detection Surface relative navigation
Safety	Safe landing site selection	Safe landing site logic Hazard detection and avoidance

PANGU Synthetic Surface Detail (top) and actual Dimorphos surface (bottom)

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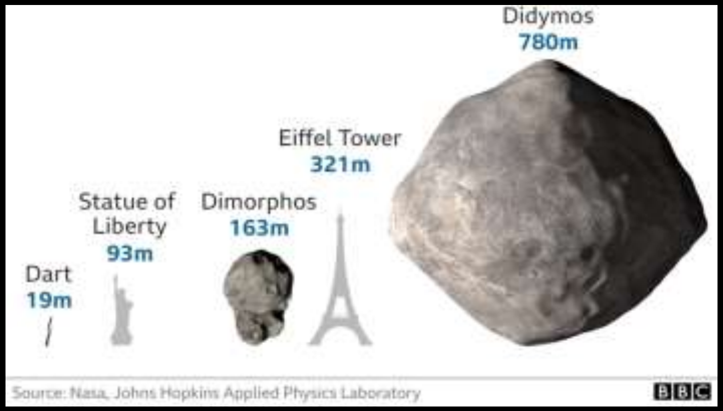
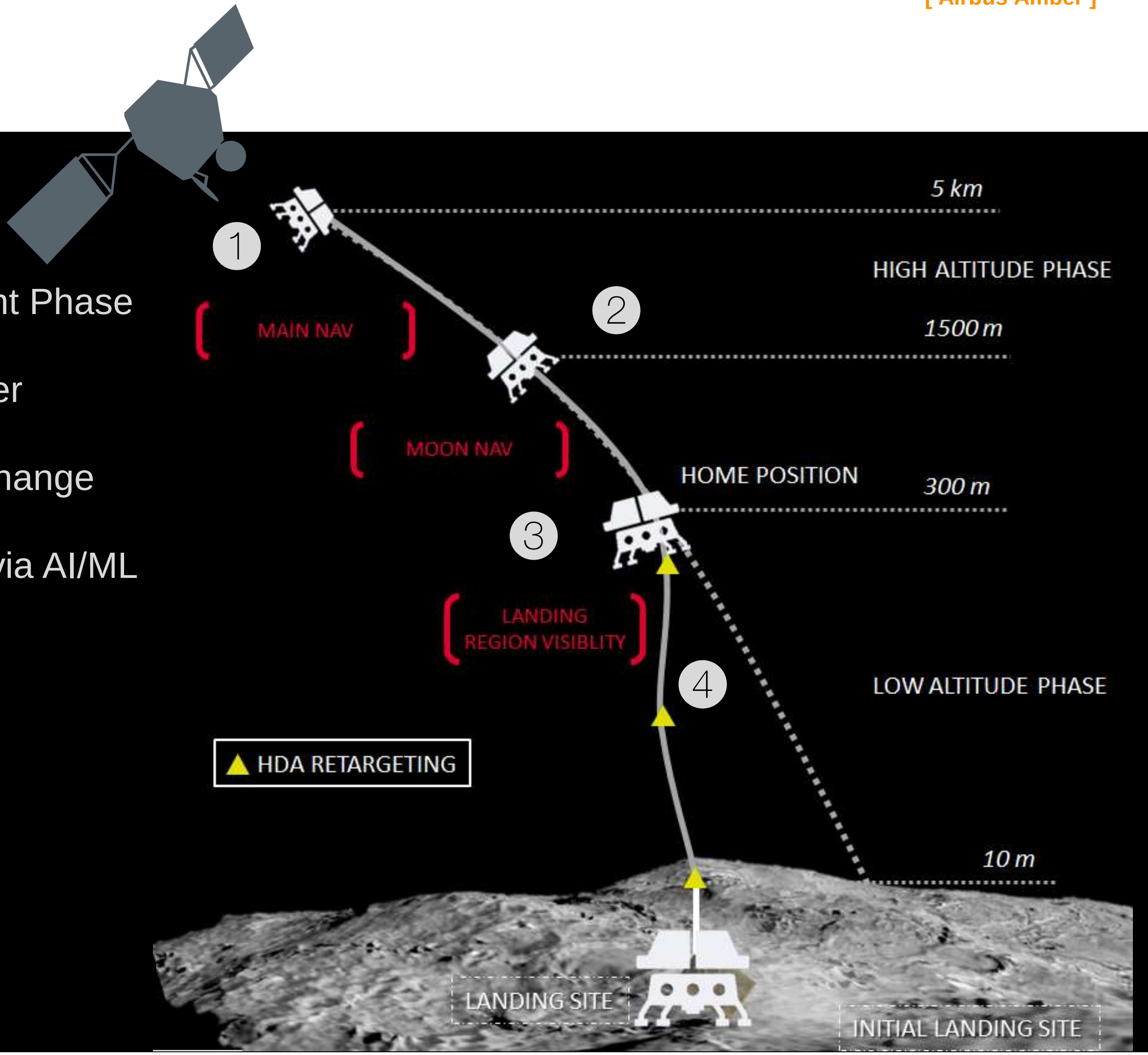
Concept of Operations

Concept of Operations

Target: landing on Dimorphos (secondary of DART/Hera scenario)

1. Initial Condition: detachment from S/C at Hera Payload Deployment Phase
2. High Altitude Phase (**HAP**): centroid-based navigation with altimeter
3. Switching point (**Home** position) where the GN&C functionalities change
4. Low Altitude Phase (**LAP**): image-based relative navigation, HDA via AI/ML





Landing operations

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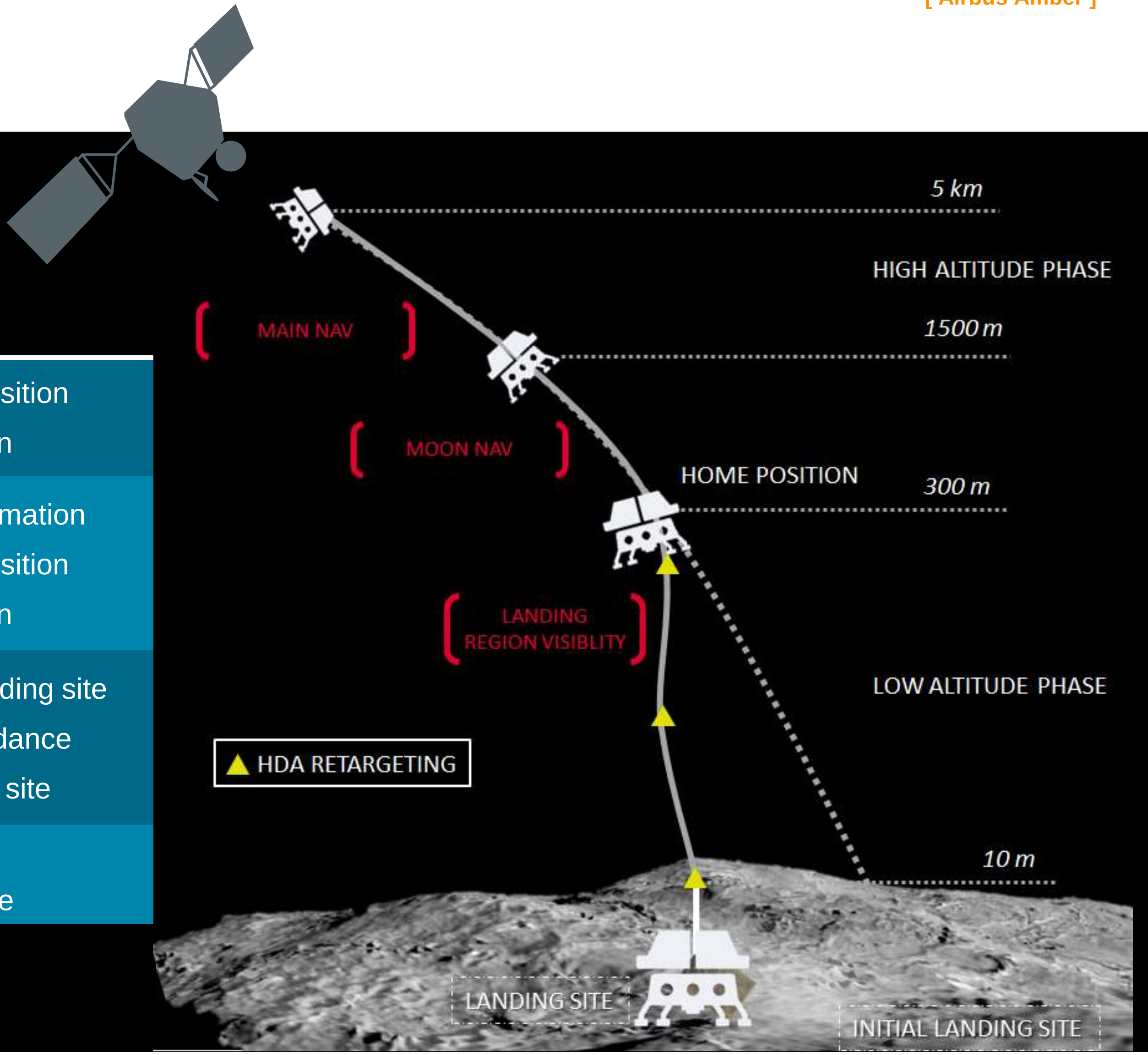
Concept of Operations

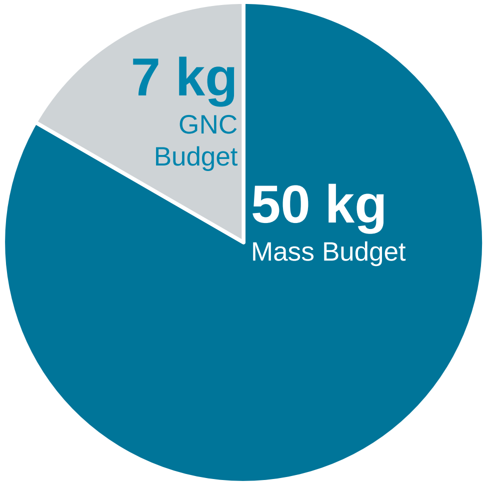
Mission Phase	Functions	GN&C Task
Separation & Commissioning	Avionics System Check Asteroid Acquisition	Descent towards Home position Pointing Home position
HAP	Approach the target body Asteroid parameter estimation Telemetry	Environment parameter estimation Descent towards Home position Pointing Home position
LAP	Landing site selection Landing preparation Hazard-relative navigation	Descent towards selected landing site Hazard detection and avoidance Pointing selected landing site
Soft Static Landing	Science surface operation	Lander stabilization Monitor estimated state



Landing operations

GNC Design

GNC Design

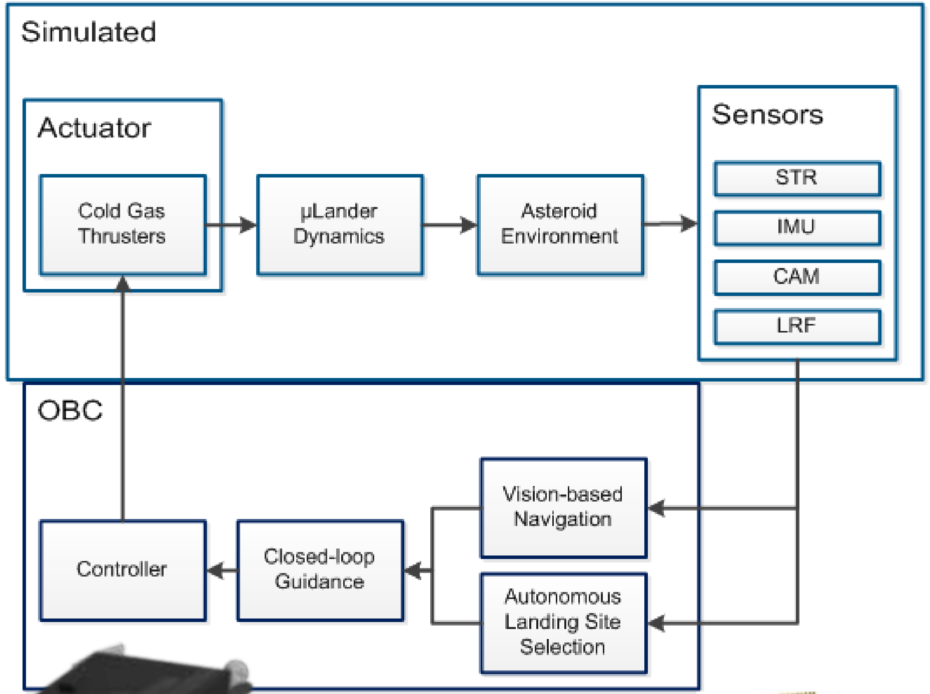


Hybrid design

- AI/Machine Learning-based combined with traditional strategies

Architecture

- Vision-based navigation (Centroid-based and Terrain Relative)
- Autonomous safe landing site selection (Hazard Detection and Avoidance)
- Closed-loop guidance

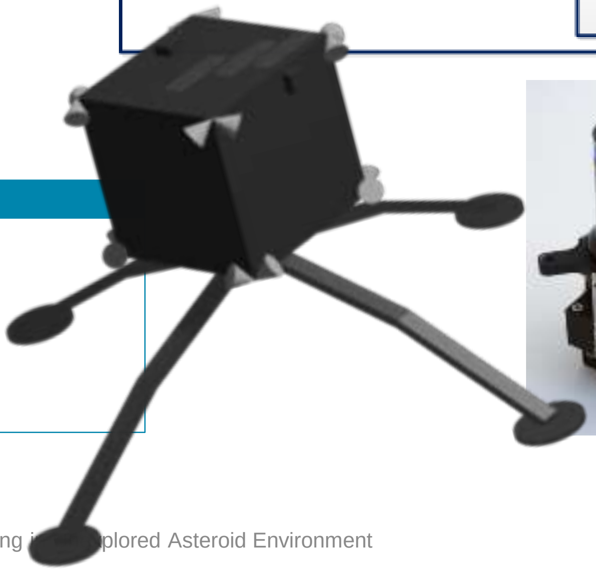


Sensor Suite (COTS)

- IMU
- Star tracker
- Laser range finder (LRF)
- Optical camera

Actuators

- Cold gas thrusters



COTS avionics

Navigation & Autonomy

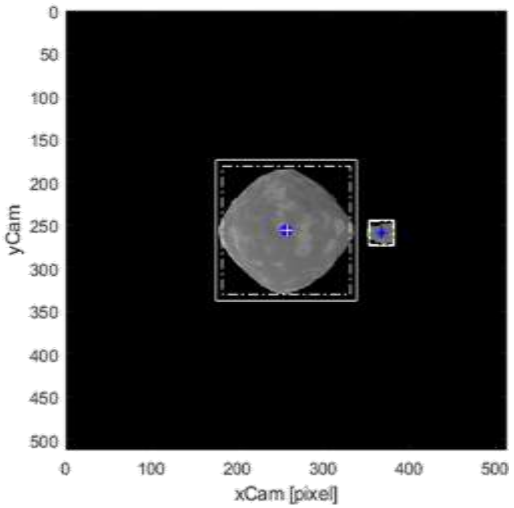
High Altitude Phase NAVigation - HAPNAV

HAPNAV

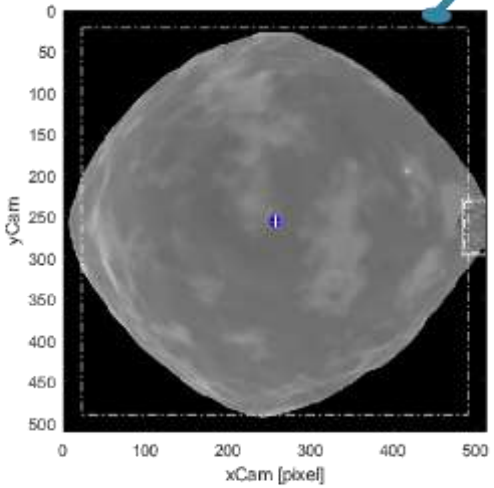
- Operational range: 5 km – 300 m
- Average descent speed: 15 cm/s

ARCHITECTURE

- 6 DoF EKF Estimation
- Expected performance: $3\sigma < 50\,m$ at HOME
- Estimated state w.r.t. binary centre of mass



Camera simulator: Main Pointing



Camera simulator: Main Pointing with Secondary limb

Sensor	Measurement	Navigation Functionalities
Star Tracker	Attitude knowledge	Classical gyro-stellar Estimation
IMU	Acceleration Angular rate	Dynamic-model replacement propagation
Optical Camera	Centre of brightness Angular size Limb	Centre of mass estimation Limb/scale fitting
Laser Range Finder	S/C surface range	Surface/body modelling

~ 5 km
Separation & Commissioning

5 km
HAPNAV & HAPGUI

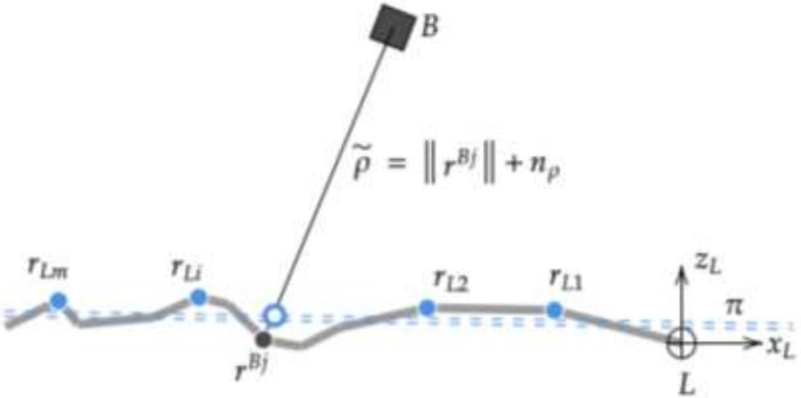
300 m
LAPNAV & LAPGUI

~ 150 m
Safe Landing Site Selection

Status

- Environment modelled
- Simulator developed
- Filter implementation ongoing

Low Altitude Phase NAVigation - LAPNAV



SLAM State $\hat{X} = \left[\hat{r}_L^{LB} \;\; \hat{v}_L^{LB} \;\; \hat{b}_a \;\; \hat{q}_{LB} \;\; \hat{b}_g \;\; \vdots \;\; \hat{r}_{L1}^{L} \;\; \hat{r}_{L2}^{L} \;\; \cdots \;\; \hat{r}_{Lm}^{L} \right]$

Lander state — Landmarks state

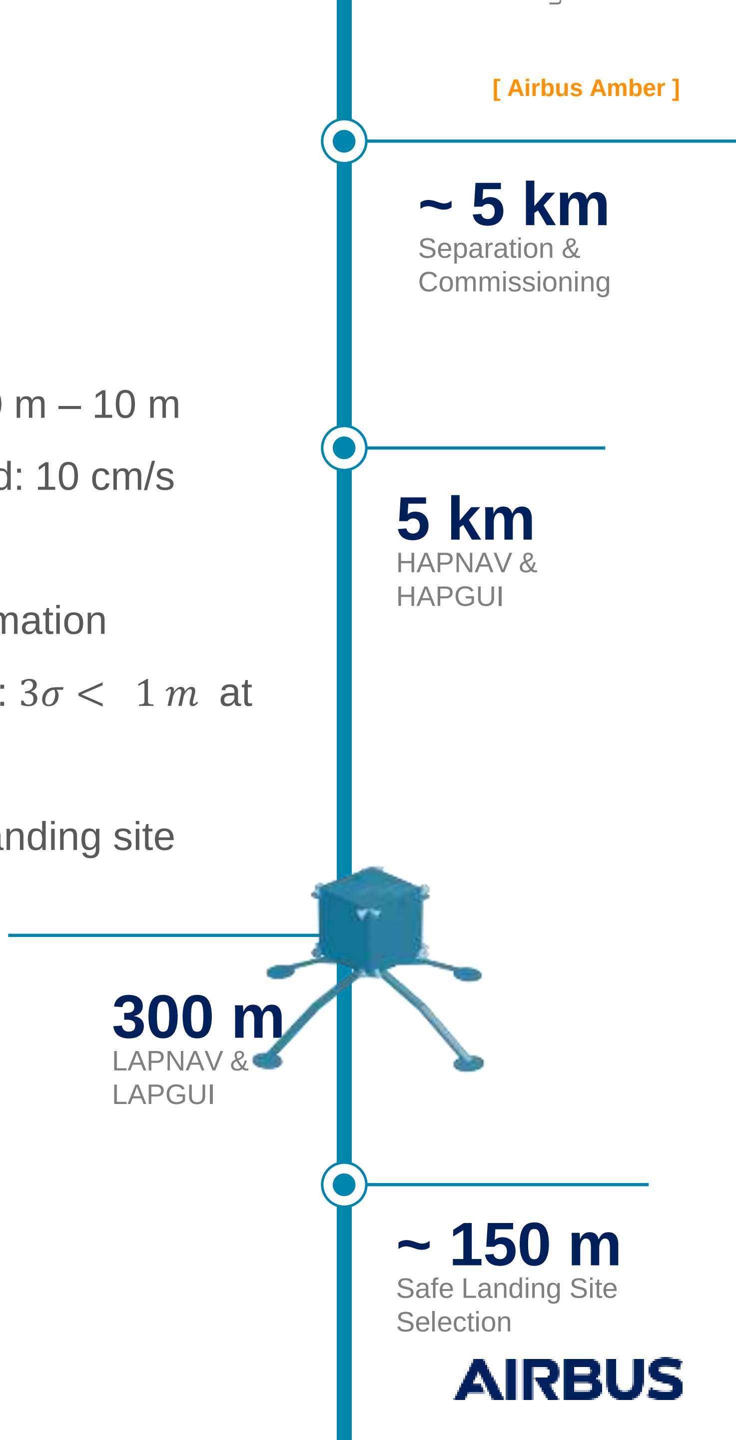
Sensor	Measurement	Navigation Functionalities
Star Tracker	Attitude knowledge	Classical gyro-stellar estimation
IMU	Acceleration Angular rate	Dynamic-model replacement propagation
Optical Camera	Hazard features	Feature extraction & tracking
Laser Range Finder	S/C surface range	Surface/body modelling

LAPNAV

- Operational range: 300 m – 10 m
- Average descent speed: 10 cm/s

ARCHITECTURE

- SLAM-EKF 6 DoF estimation
- Expected performance: $3\sigma < \ 1\,m$ at landing
- Estimated state w.r.t. landing site



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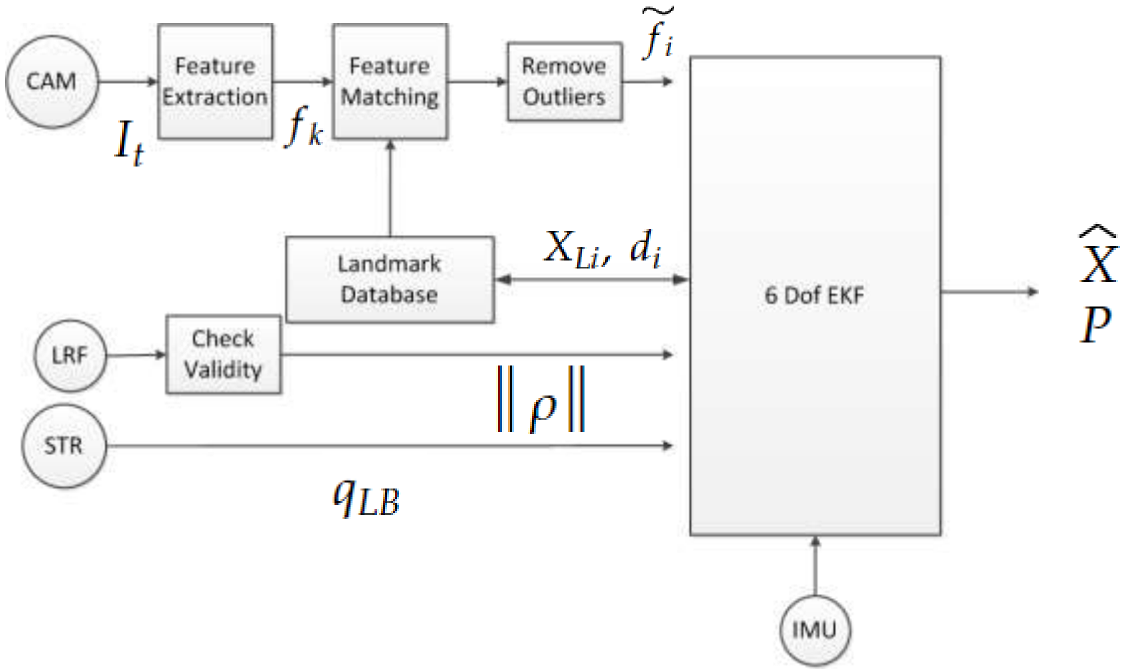
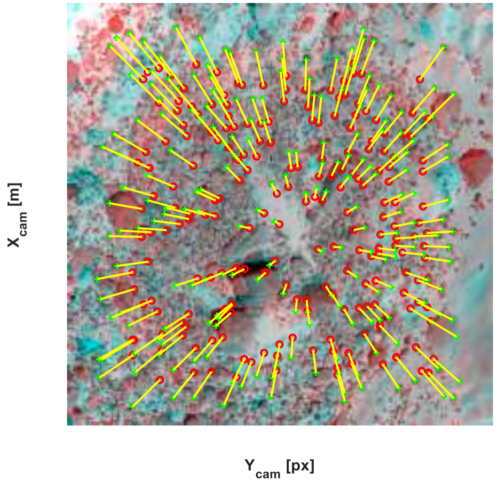
Low Altitude Phase NAVigation - LAPNAV



VBN COMPONENTS

- Tightly coupled image processing
  - Features included in the filter
- KAZE-KLT feature tracker
- Lidar-free



Tracked features KAZE-KLT features

Status

- Environment modelled
- Simulator developed
- Implemented 3 DoF solution with simulated IP
- Real IP filter implementation ongoing

~ 5 km
Separation & Commissioning

5 km
HAPNAV & HAPGUI

300 m
LAPNAV & LAPGUI

~ 150 m
Safe Landing Site Selection

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Autonomous Safe Landing Site Selection - SLSS

SLSS

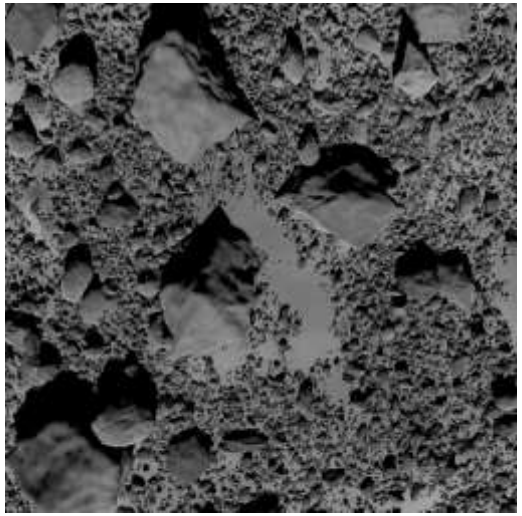
– Hazard Detection + Landing Site Selection

– Different landing criteria linked to requirements are fused

– The SLSS is run at fixed gates

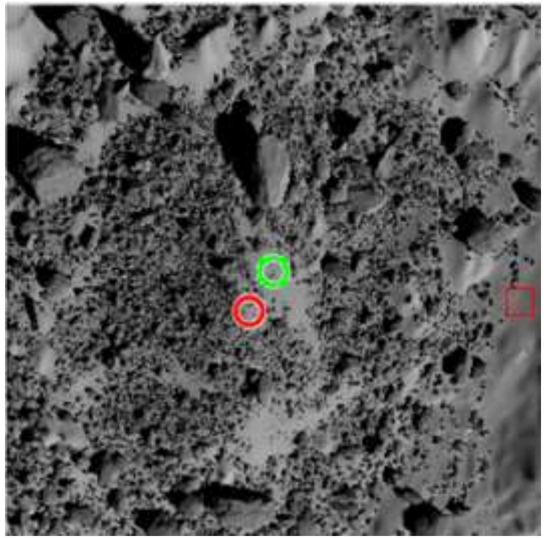
Note

Link from **Camera frame** to **L-frame** is established via *LAPNAV*



Sample input

SLSS



Sample output

Target Landing Site	(green circle)
Nominal Landing Site	(red circle)

~ 5 km
Separation & Commissioning

5 km
HAPNAV & HAPGUI

300 m
LAPNAV & LAPGUI

~ 150 m
Safe Landing Site Selection

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Autonomous Safe Landing Site Selection - SLSS

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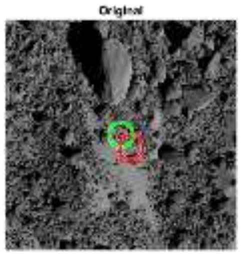
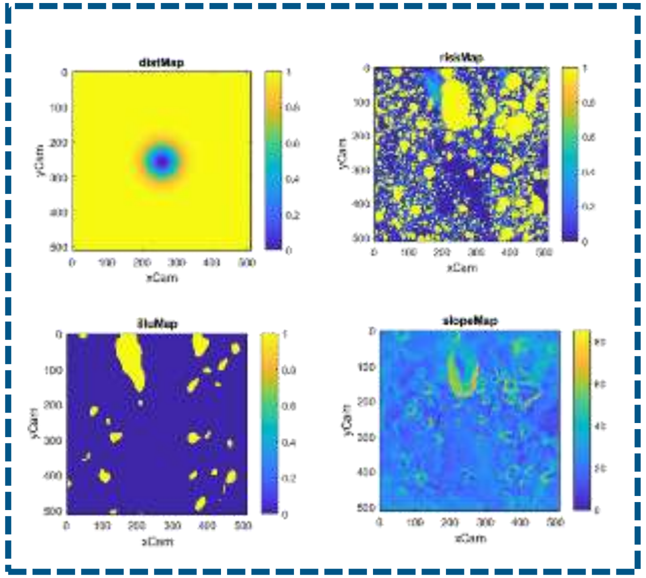
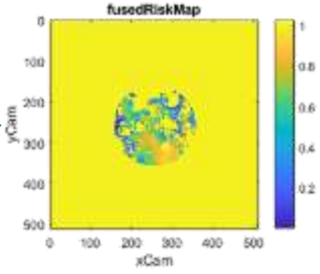
LRF





Fast Map Fusion



~ 5 km
Separation & Commissioning

5 km
HAPNAV & HAPGUI

300 m
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~ 150 m
Safe Landing Site Selection

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Conclusion & Future works

CONCLUSION

- NEO-MAPP study enables challenging **µLander**
  - Mass limitation
  - Lidar-free avionics
  - Limited prior environment knowledge
- Key-enablers for **autonomy**
  - Feature-based relative navigation
  - Machine learning hybrid HDA

NEO-MAPP Mid-term meeting

FUTURE WORKS

- LAPNAV IP implementation and performance analysis
- HAPNAV filter implementation and analysis
- End2end closed-loop integration and testing

REFERENCES

- Caroselli, E., Belien, F., Falke, A., Curti, F. and Foerstner, R., 2022. Deep Learning-based Passive Hazard Detection For Asteroid Landing In Unexplored Environment. *AAS GNC 2022 Conference*,.
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Thank you

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