GNC System for ADR Missions

17th ESA Workshop on Avionics, Data, Control and Software Systems

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CLEARSPACE-1:
Debris Removal

Removal of a launch vehicle payload adapter

First non-prepared removal

Commissioned by the European Space Agency (ESA)

CLEAR:
Multi-Debris Removal

Removal of two UK-licensed derelict spacecraft

Designed for refueling and re-use

Phase B contracted by the UK Space Agency (UKSA)

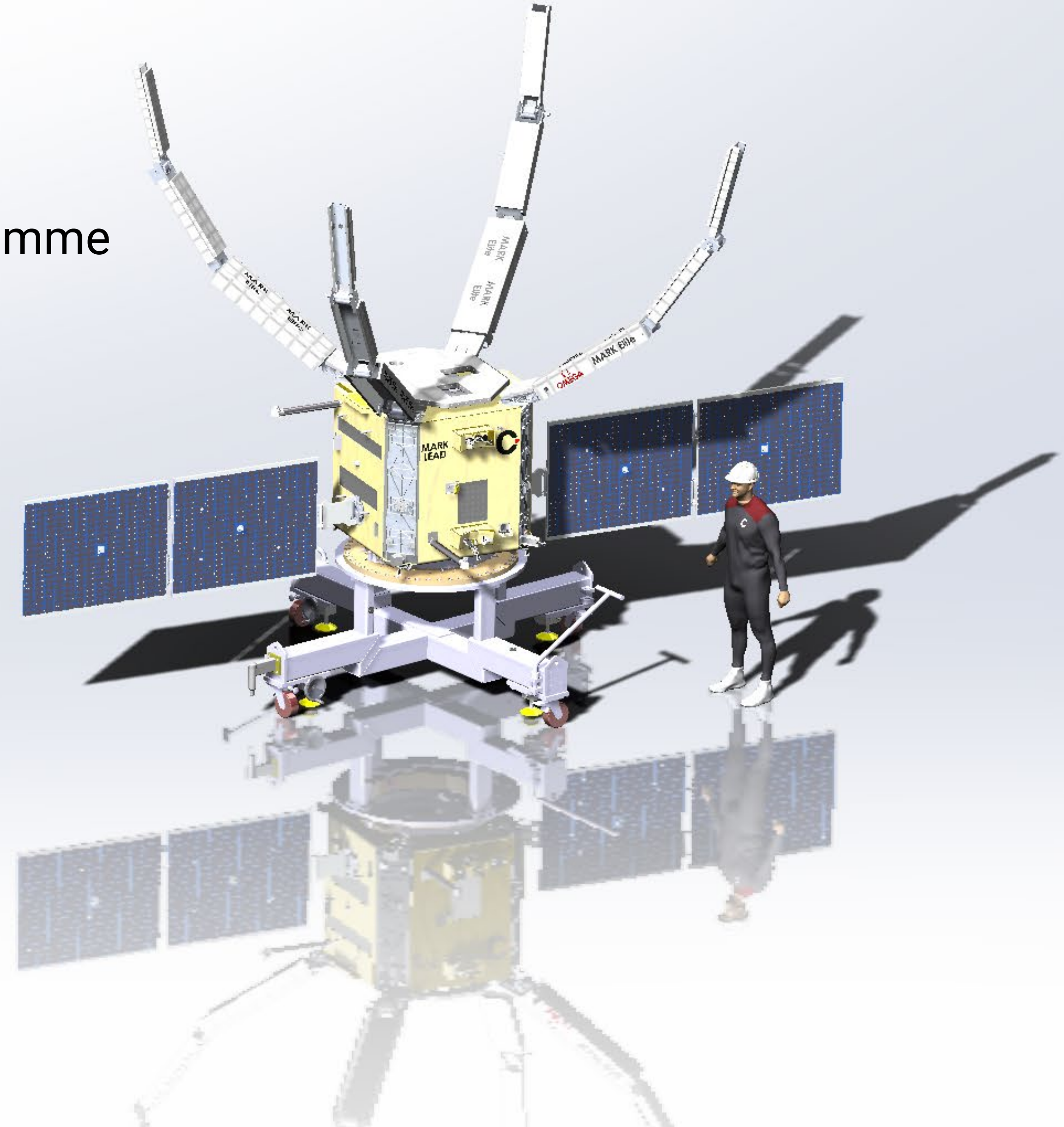
ClearSpace-1

Funded within ESA's ADRIOS programme

700kg wet mass

Handles different tumbling rates

Adaptable for different types of objects

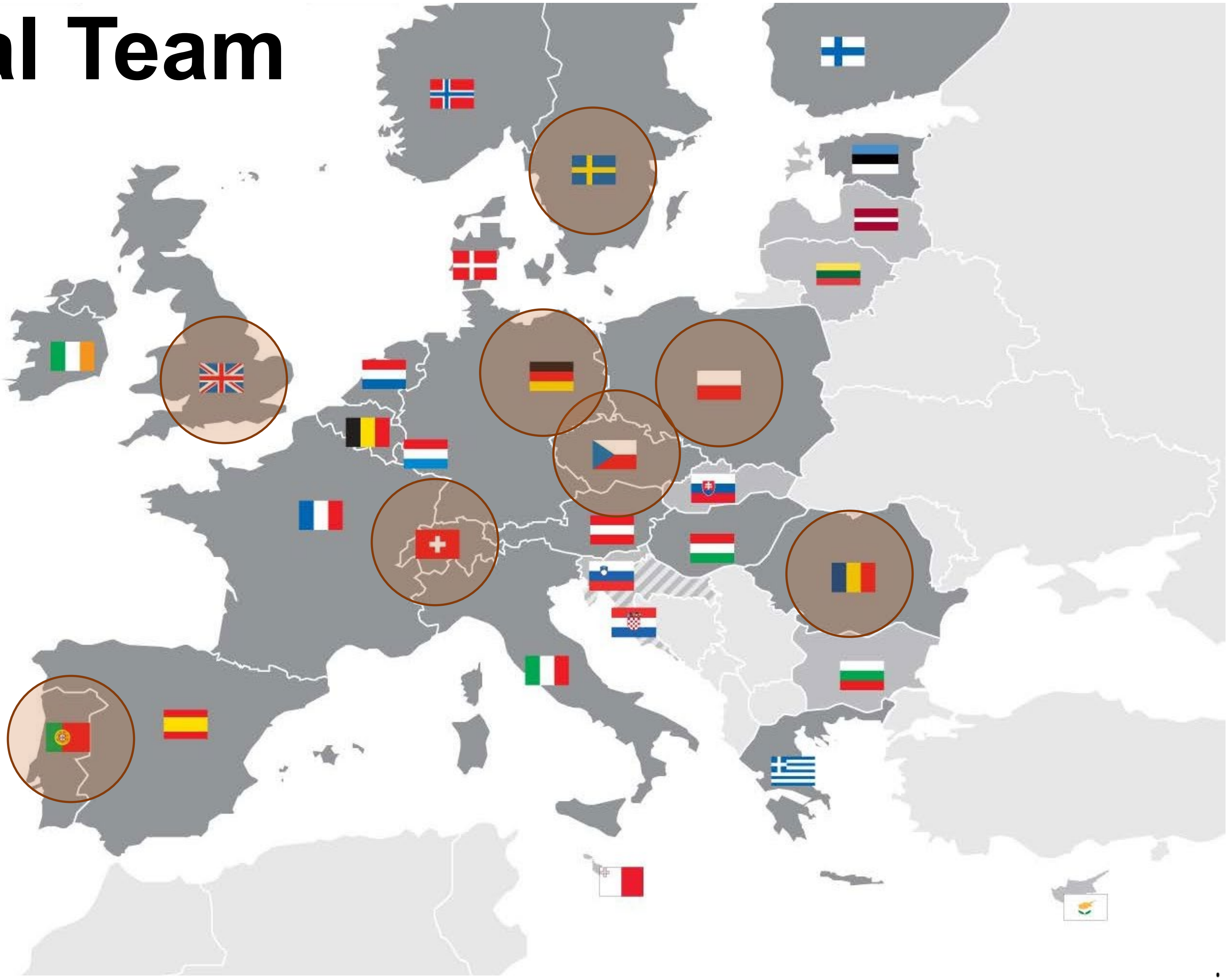


Industrial Team

GNC

deimos
elecnor group

Critical
software



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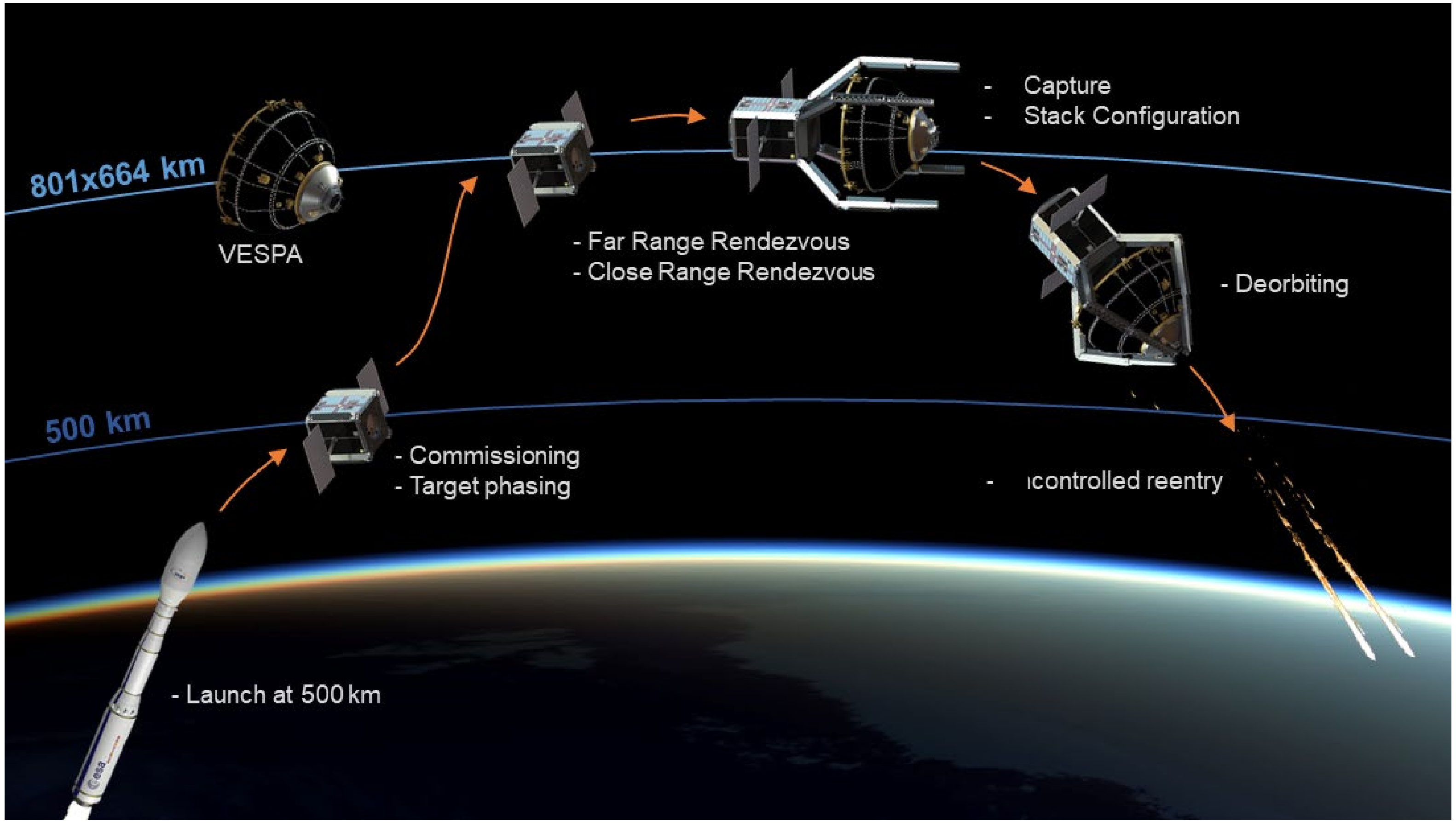
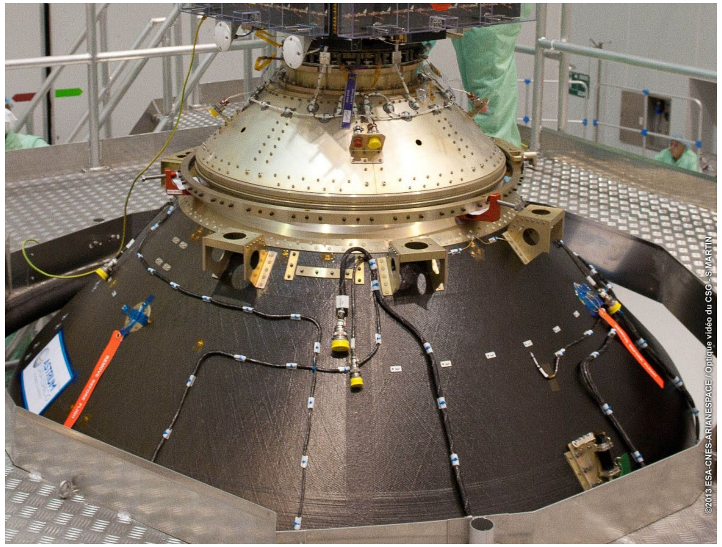
Concept of Operations

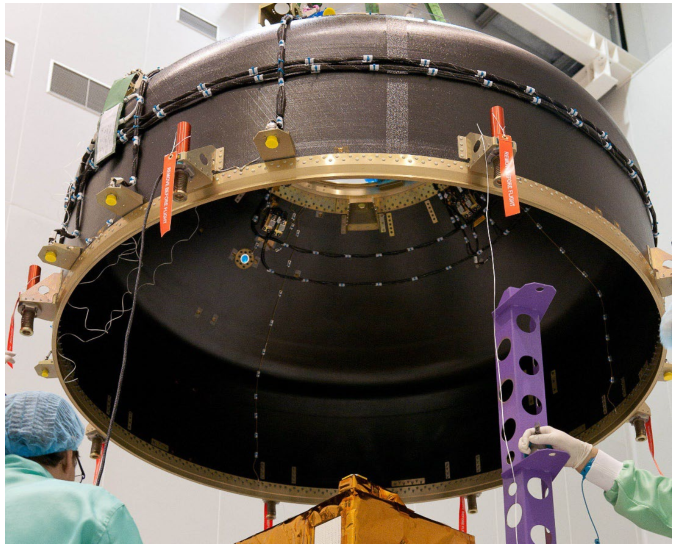
- LEOP/commissioning at low altitude
- Orbit phasing
- Rendezvous
  - Far-range detection and approach relying on Angles-Only Navigation
  - AON complemented with ranging device at mid-range to enable simple and robust fly-around.
    - ➢ close-range navigation commissioning
    - ➢ additional sensor testing
  - Challenging close-proximity operations relying on forced motion and precise close-range navigation
    - ➢ commissioning of key components for the capture
    - ➢ additional technology demonstrations
- Capture & detumbling
- Stacked controlled re-entry



Target VESPA

- Design
  - as-built configuration and documents not available to the project
  - limited access to pictures and mass properties tables
  - ClearSpace reconstructed baseline structure based on pictures and material information
  - Mass ~ 110 kg
  - 1.8-m height, 2.1-m base diameter

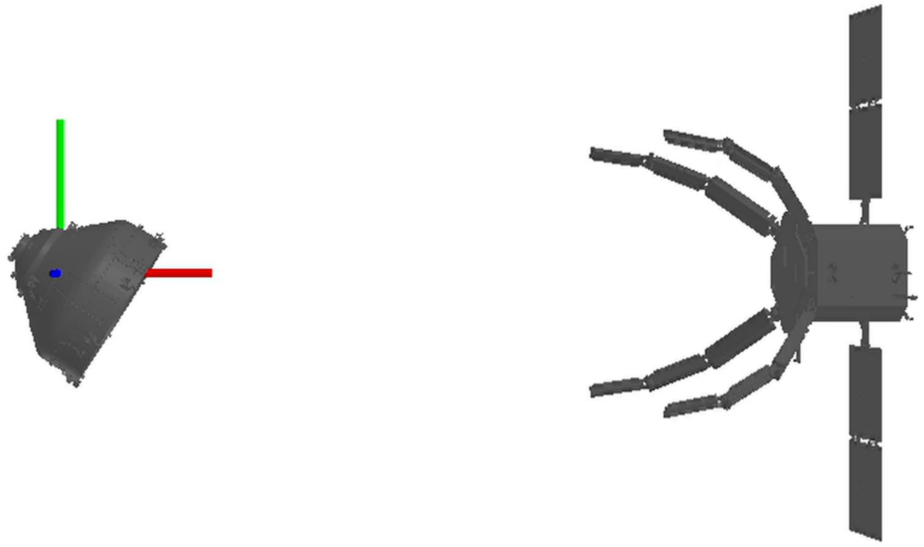




GNC Challenges

- Noncooperative target: no exchange of information, no marker to ease the navigation, attitude not stabilized.
  - What is the best way to capture the target?
  - What is the most appropriate sensor suite for the relative navigation?
- Unknown state of the target in orbit
  - Tumbling motion and rate?
  - Surface characteristics after several years in orbits?
- Propulsive solution needs to reach agility, precision for rendezvous, and high-thrust for controlled re-entry
- Viability of the commercial mission
  - High level of autonomy needed to reduce the operational efforts and infrastructure
  - Low recurring costs
- Critical operations with potentially severe consequences
  - High reliability for critical equipment
  - Redundancy
  - Complex FDIR mechanisms

How to Capture The Target?



straight-line approach

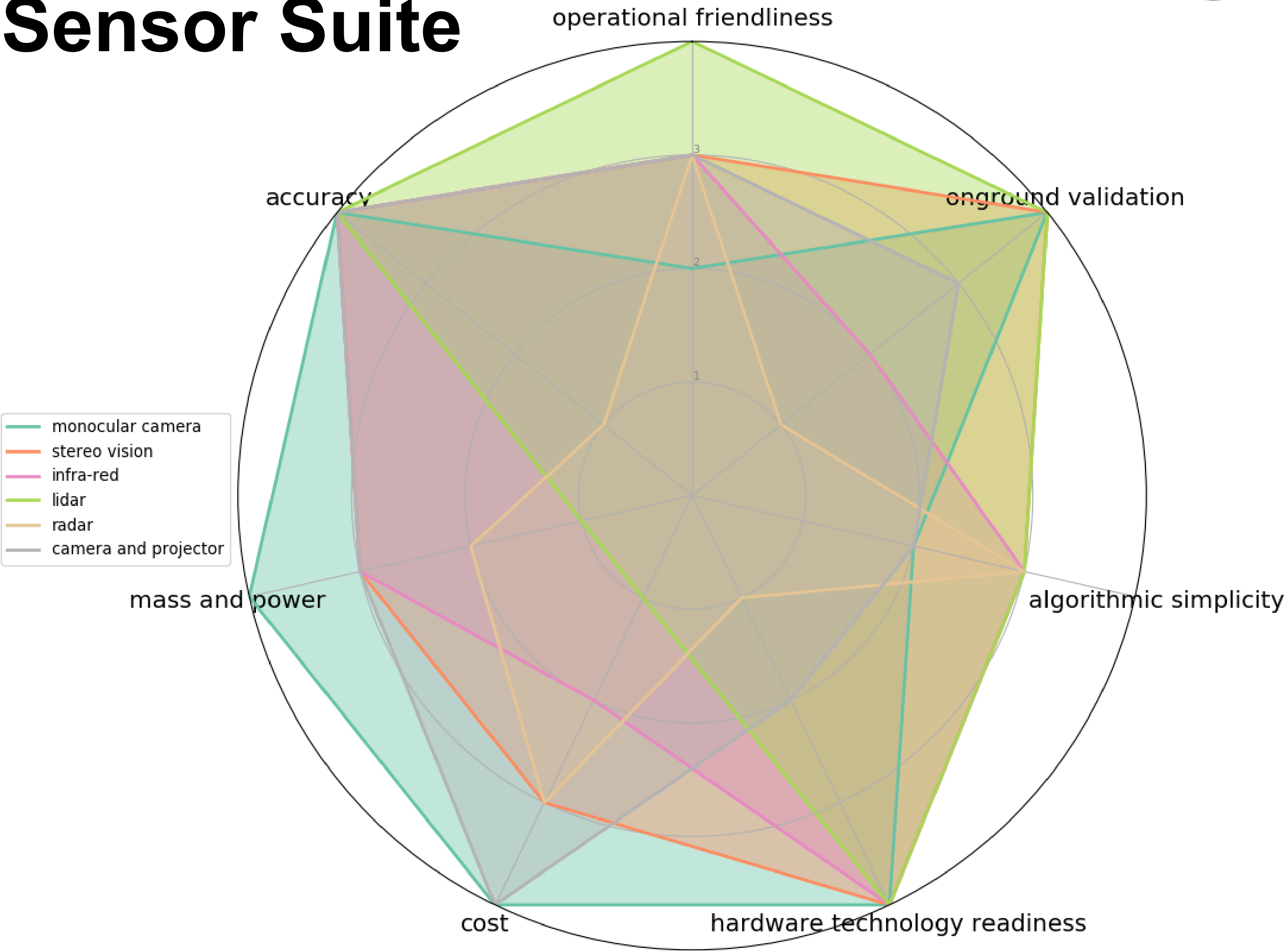
- algorithmic simplicity: attitude-agnostic capture
- less demanding control authority

motion synchronization

- limited energy during impact
- possibility to define a desired direction of capture avoiding obstacles
- simplification of the validation of the capture

The Quest for Optimal Close-Range Sensor Suite

- ClearSpace-1 relies on **monocular camera in the visible spectrum**
- This is natural choice to achieve low recurring costs for a commercial mission, but induces additional operational difficulties
- Additional sensors are embarked as technological demonstration



Advanced Guidance, Navigation and Control

Real-time Navigation

- target detection
- distance measurement at cm level
- state of the art pose estimation algorithms and sensors.

Onboard Guidance

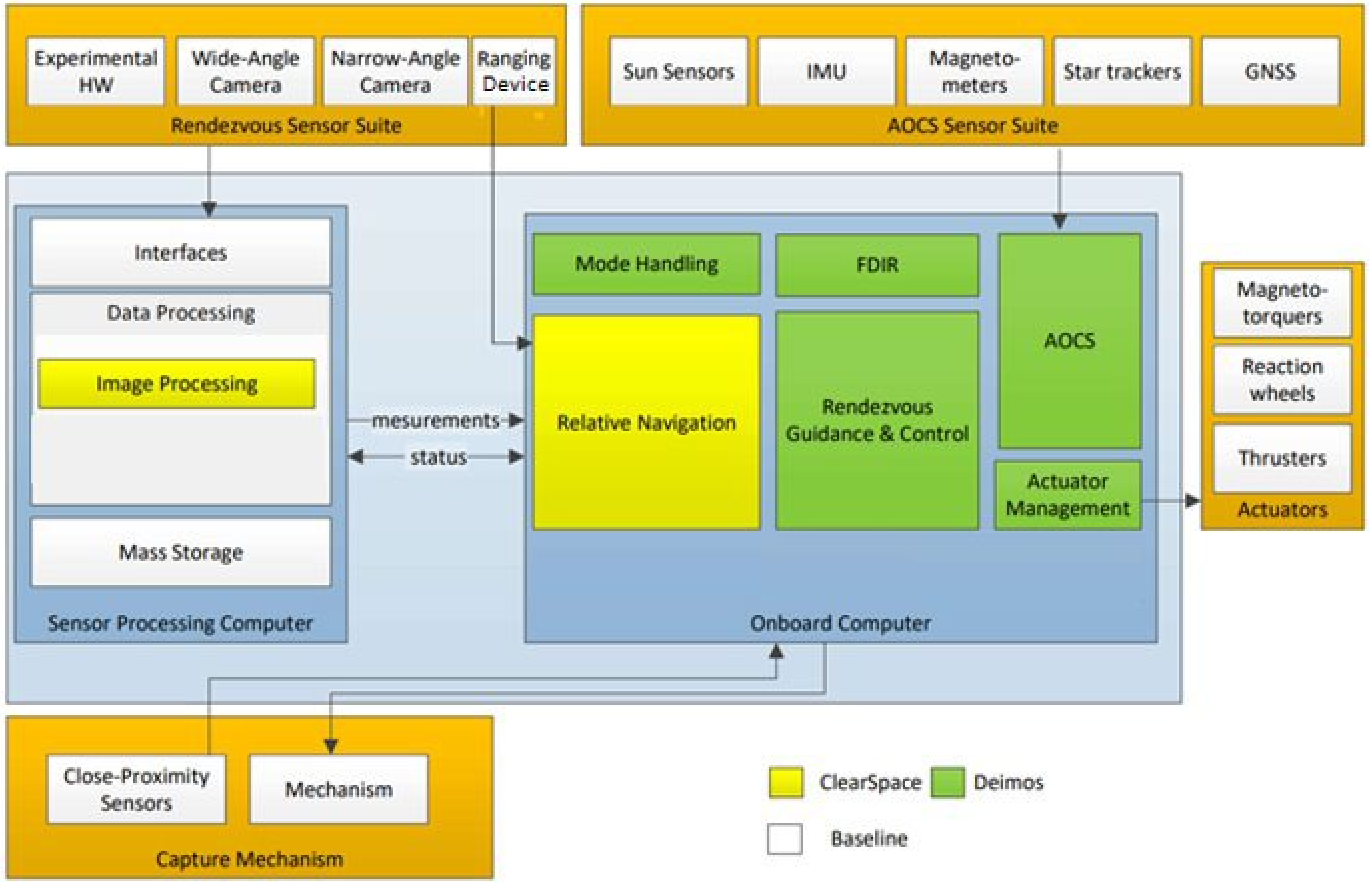
- advanced path planner to ensure synchronization while satisfying other constraints
  - proper illumination
  - available control authority
  - operational window with ground coverage

Robust Control

- Ensures that the highly dynamical guidance trajectory is followed, even if the presence of:
  - actuation and navigation errors
  - flexibility of the structure
- Control accuracy at cm level necessary for capture.

GNC Architecture

- Typical AOCS sensors and actuators, complemented with rendezvous sensor suite
- Different relative navigation sensors to cover the different regions of the rendezvous
- Distributed architecture with dedicated sensor processing computer for computationally intensive image processing

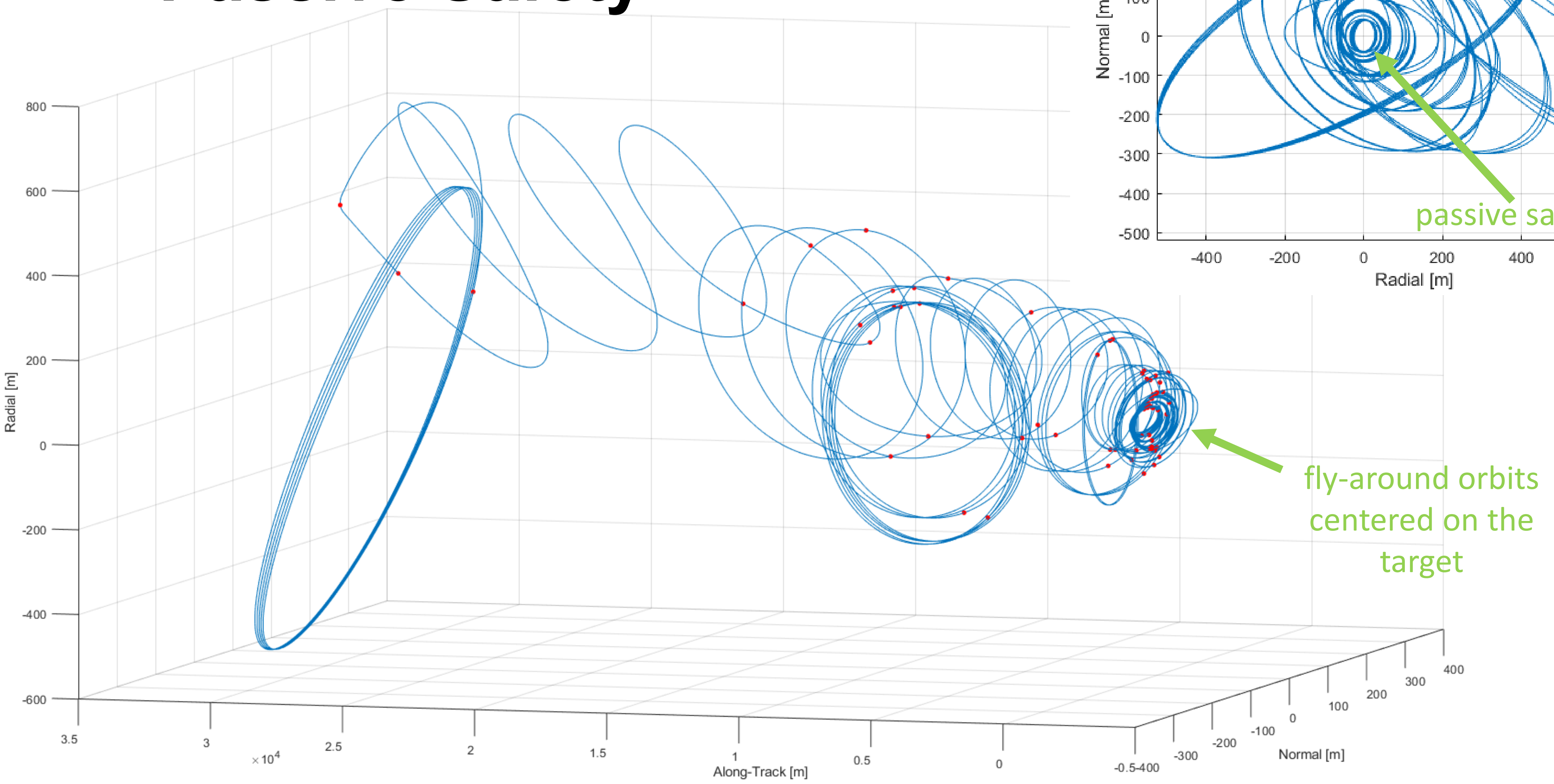


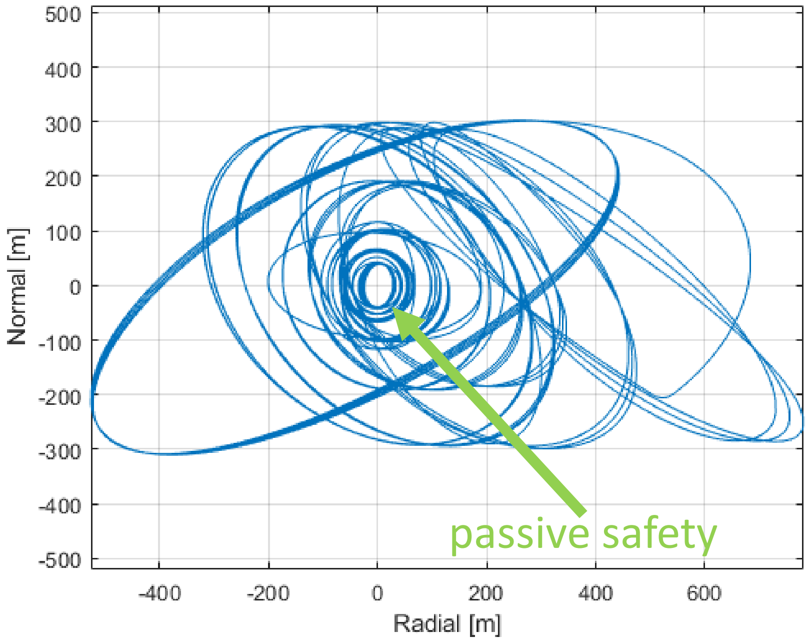
GNC Functions

Many functions to cover the different phases of the mission and the rendezvous

- Absolute navigation: orbit and attitude knowledge
- Attitude guidance: sun pointing, ground pointing, maneuvers, target pointing
- Relative navigation: far-range (AON), mid-range (AON+range), close range (pose estimation)
- Rendezvous guidance: impulsive or complex motion synchronization path, phase transitions
- Precise and robust 6DoF relative control
- Stack detumbling and control after capture
- Actuator management: momentum management and 6DoF thruster management

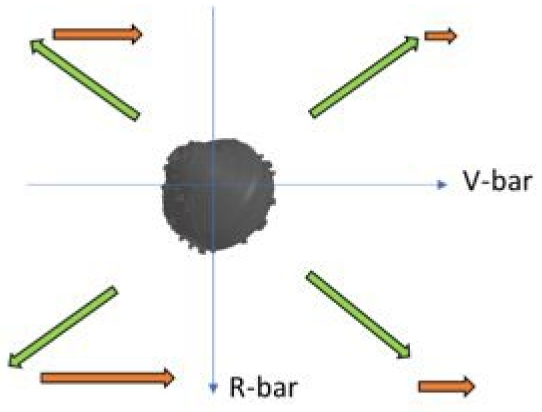
Safety During Rendezvous: Passive Safety

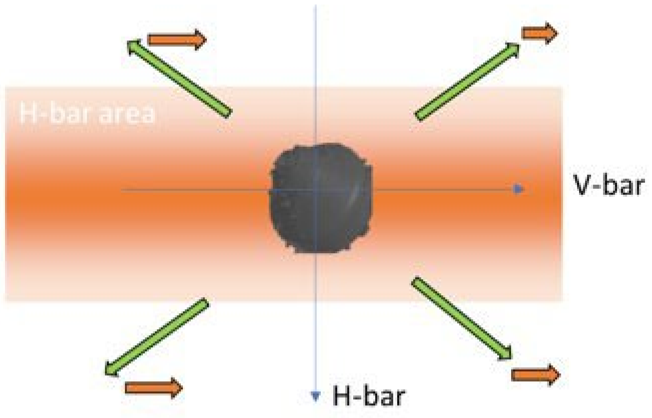




Safety During Rendezvous: Active Collision Avoidance

- Passive Safety can no longer be used in close proximity
- Active collision avoidance capability is mandatory
- Capture along a specific direction in target body frame makes the CAM design complex
- CAM strategies relies on two maneuvers to first move away from the target and then ensure long term safety
- The CAM is dependent on the coarse knowledge of the relative state





The Cost of Safety

- Safety measures are often competing with low recurring costs
- Enhanced onboard intelligence may limit the number of hardware device, but at the cost of algorithm complexity, which in turns results in additional validation efforts
- The trade-off is not trivial

	Hardware solution	Algorithmic solution
Relative navigation integrity check	Combination of independent sensors (e.g. lidar vs camera)	Dynamical consistency check
Propulsion failure detection	Precise accelerometer	Monitoring of abnormal behavior of the GNC closed-loop
Thruster failure recovery	Switch to redundant branch	Single thruster failure detection and isolation

- Additional sources of cost increase: hardware QA/PA standards, software criticality

$\Rightarrow$ need for a proper balance between safety during rendezvous and commercial viability of ADR missions

Conclusion

- ClearSpace-1 is a precursor mission paving the way for Active Debris Removal
- The mission is very complex because of the noncooperative nature of the target
- The current design aims at capturing a target in a synchronized state
- The GNC development enters now the detailed design phase

Thank you!

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