FUTURE RENDEZVOUS & ON-ORBIT SERVICING MISSIONS BY AUTONOMOUS GNC & VISION-BASED NAVIGATION

CLEAN SPACE INDUSTRY DAYS
ESTEC (NOORDWIJK, NL)
10-14/10/2022

ThalesAlenia Space
a Thales / Leonardo company

Date: 07/06/2022
Ref: 0003-0003057786
Template: 83230347-DOC-TAS-EN-009

This project has received funding from the European Union's H2020 research and innovation programme under grant agreement No 101004346.

AGENDA

/// Overview of key technologies and avionics architectures developed by Thales Alenia Space

/// Two main milestones presented

- Horizon 2020 OG7 | EROSS (2019-2021)
- Horizon 2020 OG12 | EROSS+ (2021-2023)

/// One major program to come

- Horizon Europe | EROSS In-Orbit Demonstration

Date: 03/10/2022
Ref: Not referenced
Template: 83230347-DOC-TAS-EN-010

H2020 OG7 - EROSS

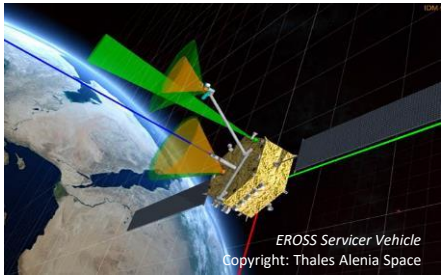
Ground demonstrations of GNC & Robotics Technologies towards Rendezvous and On-orbit servicing missions 2019 – 2021

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821904

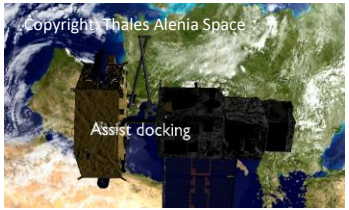
EROSS Context

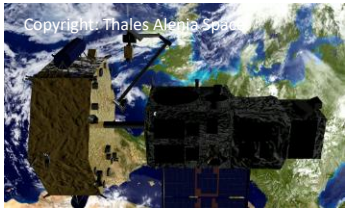
EROSS European Robotic Orbital Support Services

- **EROSS "ID Card"**
  - **Context:** H2020 - European Commission
  - **Prime:** **Thales Alenia Space**
  - **Partners:** GMV, SINTEF, NTUA, PIAP, SENER, SODERN, SAS
  - **Budget:** 4 M€
  - **Topic:** Robotic technologies for On-Orbit Servicing



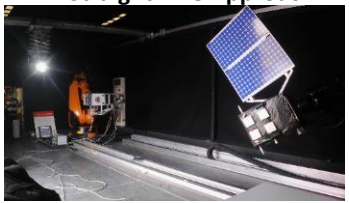
Numerical Validation



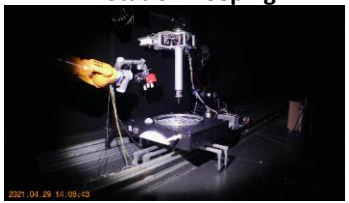


Experimental Validation

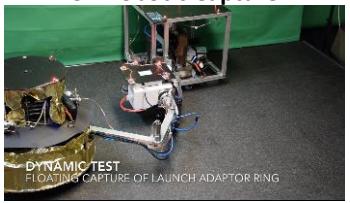
1 - Straight Line Approach



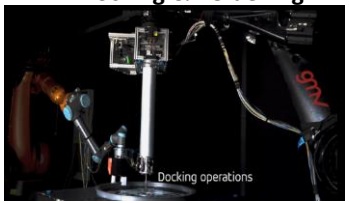
2 - Station Keeping



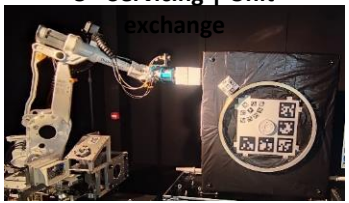
3 - Robotic Capture



4 - Docking & Refuelling

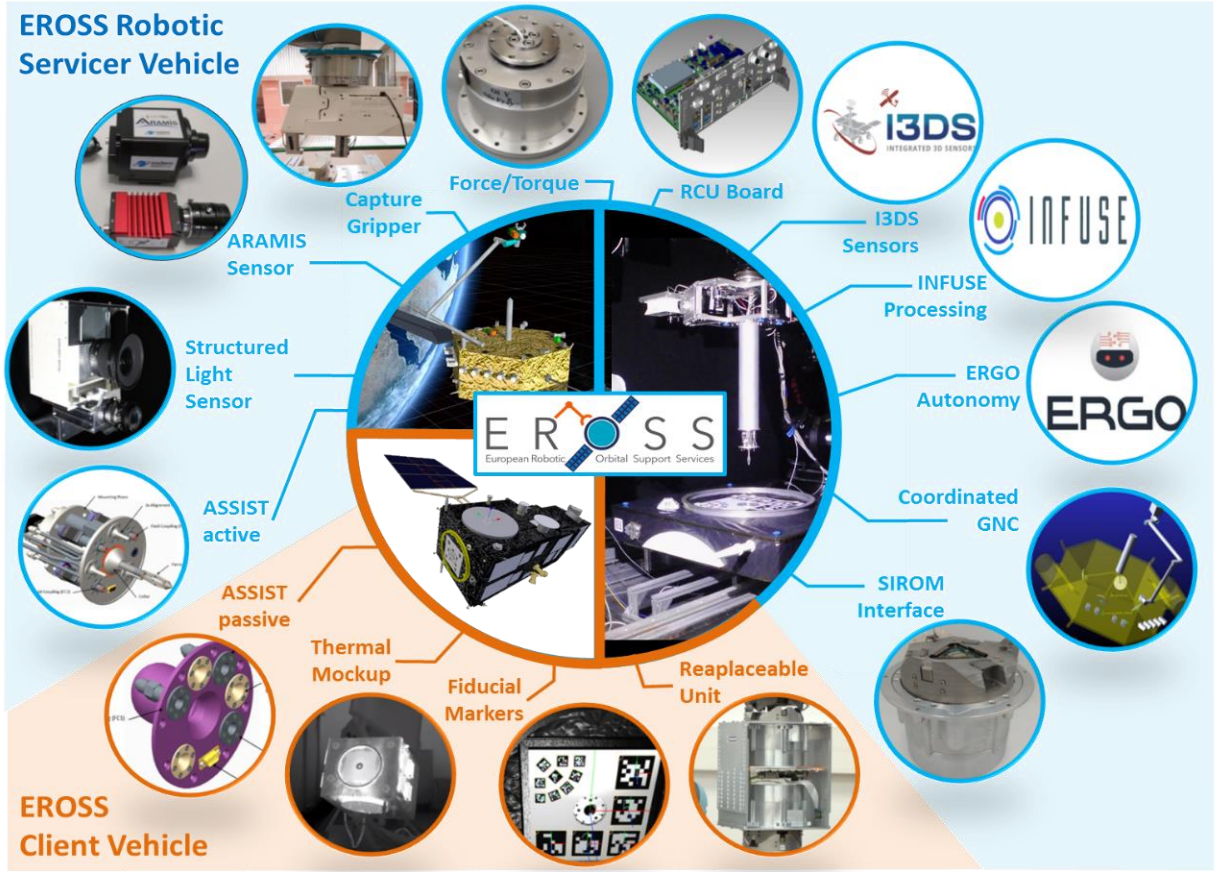


5 - Servicing | Unit exchange



100m **20m** **2m** **Contact**

« EROSS in a nutshell »

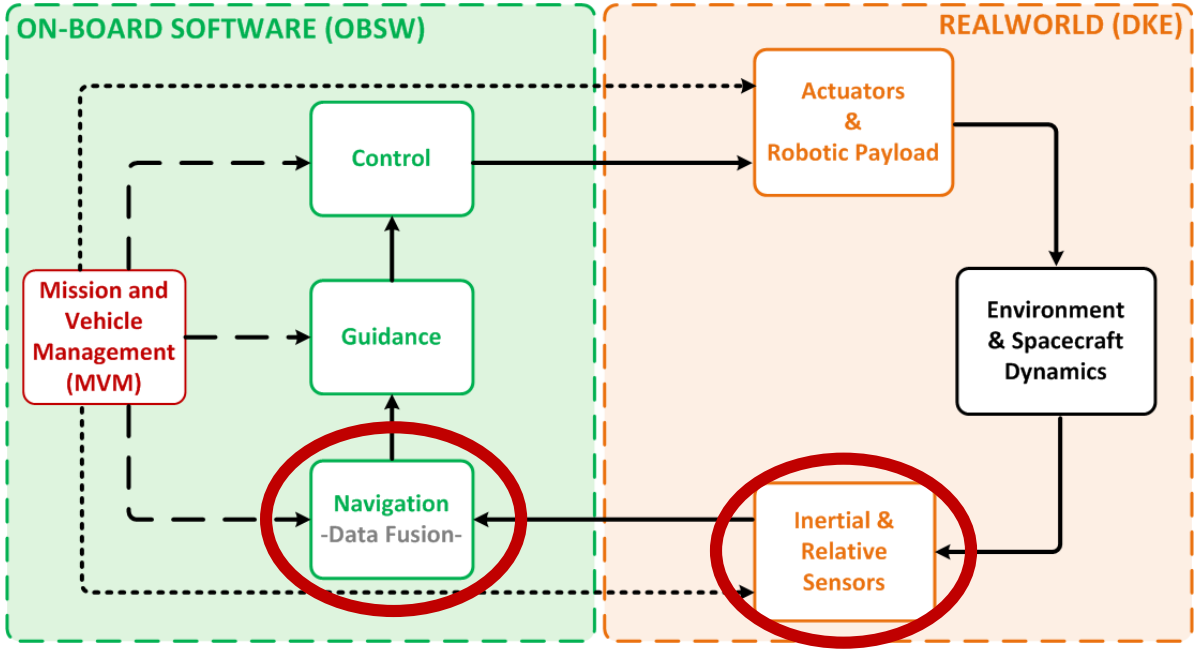


❑ EROSS Main Achievements

1. TRL raising of the key robotic building blocks (BB)
2. Building Blocks Integration in a System Demonstrator
3. Coordinated Robotic GNC architecture of Platform/Arm
4. Autonomy raised to E3 level for safety
5. **Closed-Loop demonstration of performance & autonomy with Vision-based Navigation** (*incl. contingency*)

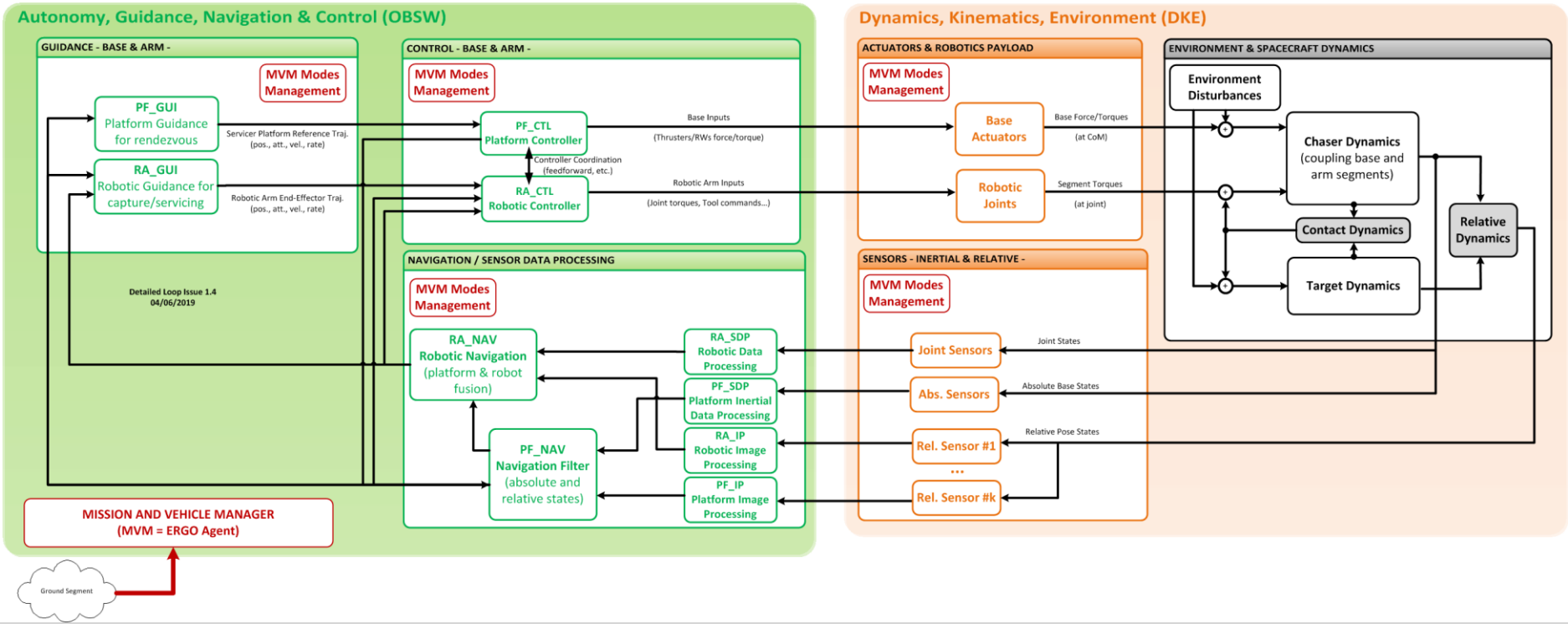
EROSS Guidance, Navigation & Control (GNC)

- Overall GNC Loop : “coordinated” Platform & Robotic controllers
- Vision-based Navigation = Image Processing + Navigation Filter



EROSS Guidance, Navigation & Control (GNC)

❑ Detailed GNC Loop : "coordinated" Platform & Robotic controllers



EROSS Sensors Selection for rendezvous

- **Vision-based Navigation = Image Processing + Navigation Filter**
  - **2x Image processing solutions** *(used separately)*
    - **INFUSE (SpaceApplicationServices)**
    - **ARAMIS (Sodern)**
  - **1x Navigation filter by Thales Alenia Space :**
    - **data fusion (inertial+relative)**
    - **propagation/filtering with asynchronous measurements**

EROSS Vision-Based Navigation

❑ "Vision-based Navigation" = Image Processing + Navigation Filter

- **Development Phase**
  - **STEP A.1 : Set up Image Generation tool**
    => SPICAM by Thales Alenia Space
    => Visible & Thermal images
  - STEP A.2 : Processing design & tuning
    => INFUSE solution by Space Applications Services
    => ARAMIS solution by SODERN
  - STEP A.3 : Delay & Noise model equivalence in open loop
  - STEP A.4 : Navigation Filter and Controller design & tuning

- **Validation Phase**
  - STEP B.1 : [MIL] Numerical validation in closed-loop
  - STEP B.2 : [SIL] Image Processing comparison with noise model
  - STEP B.3 : [PIL] Image Processing code deployment on RCU
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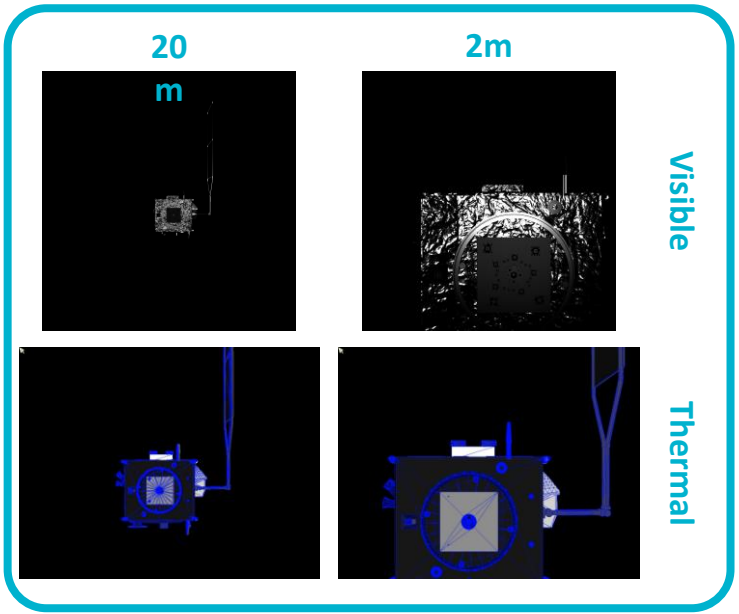

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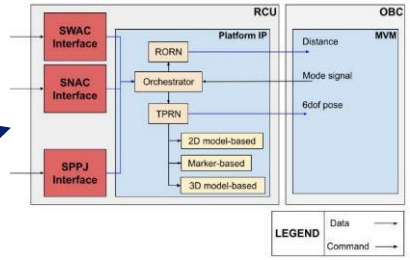

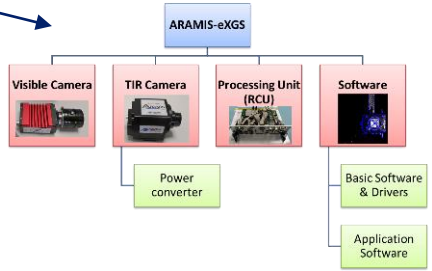

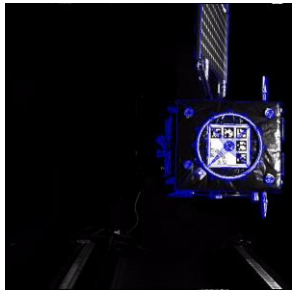

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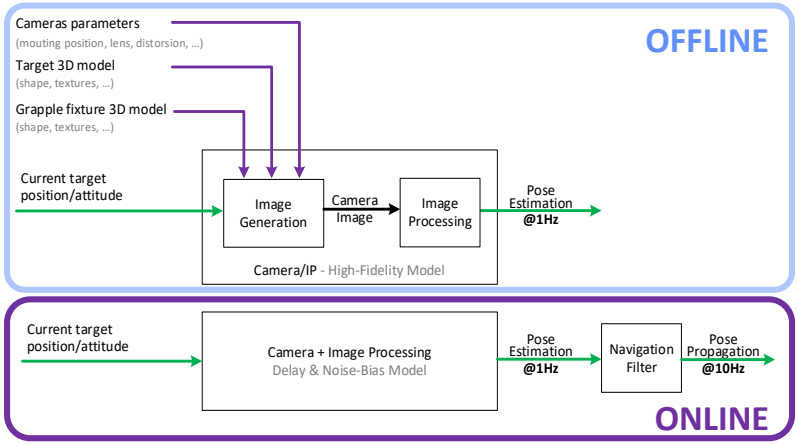

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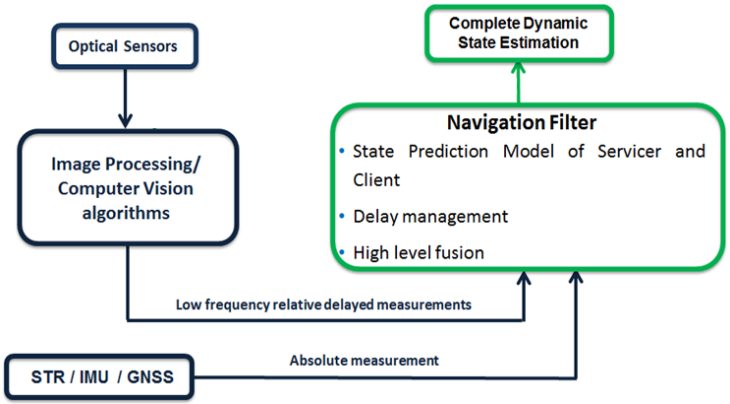

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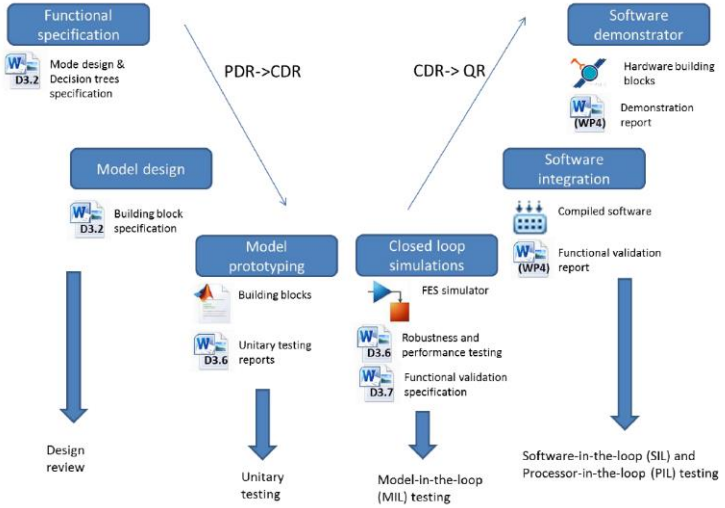

Model-in-the-loop (MIL) | Software-in-the-loop (SIL) | Processor-in-the-loop (PIL) | Hardware-in-the-loop (HIL)

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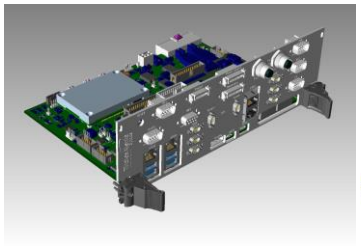

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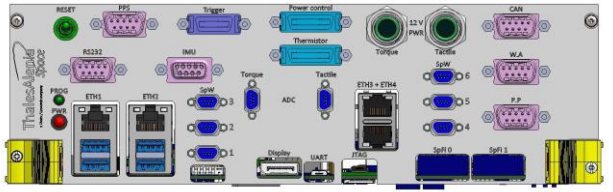

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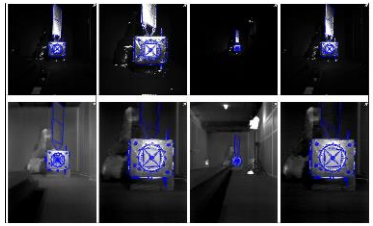

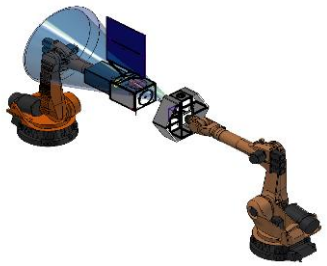

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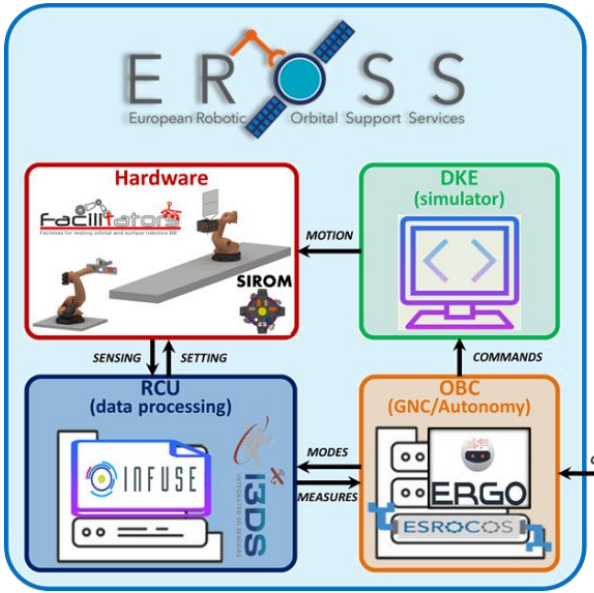

OG = "Operational Grant" = *Consortiums of past H2020 projects*

EROSS Building Blocks Integration

❑ Main Outcomes

- **Integration of previous H2020 SW/HW Building Blocks in the frame of On-Orbit Servicing scenario.**
- Recording of numerous datasets to characterize visual navigation solutions in visible & thermal spectrum
- Demonstration of the rendezvous approach in autonomous closed-loop with a visual navigation chain
- Demonstration of the autonomy to handle nominal and contingency scenarios in case of failure

		MIL	SIL	PIL	HIL
Main Components	GNC Algorithms	Matlab model	Compiled C Code in PC	Compiled C Code in OBC	Compiled C Code in OBC
	MVM/ERGO	Emulated	TASTE compiled in PC	TASTE compiled in OBC	TASTE compiled in OBC
	Image processing	Emulated	Emulated	INFUSE running in RCU (I3DS)	INFUSE running in RCU (I3DS)
	Sensors	Emulated SpiCam	Emulated SpiCam	Emulated SpiCam	SWAC/SNAC camera
	Actuators	Emulated	Emulated	Emulated	Emulated and replicated by robots
	Spacecraft dynamics				

- Model-in-the-loop (MIL)
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- Processor-in-the-loop (PIL)
- Hardware-in-the-loop (HIL)

EROSS Vision-based Datasets

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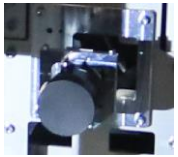
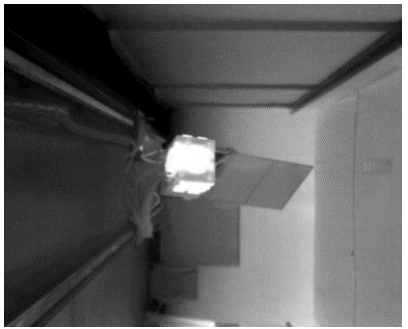


Visible

Thermal



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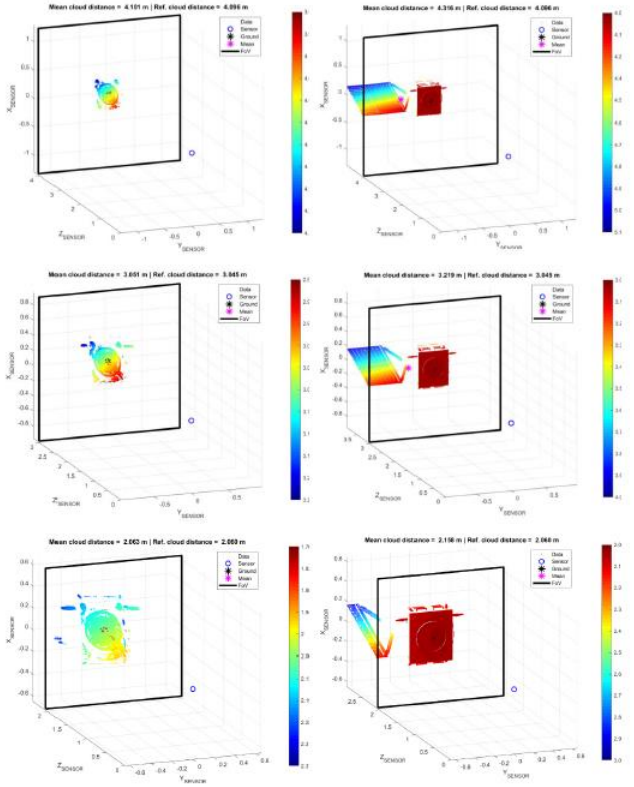
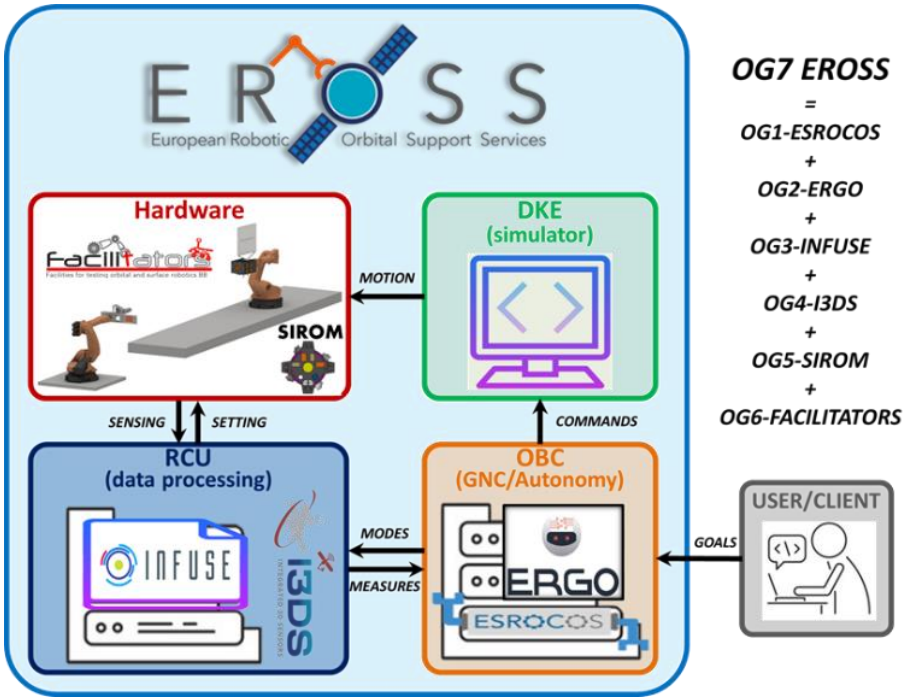
« Structured Light »
3D Dataset



EROSS Closed-Loop Results

❑ Main Outcomes

- Integration of previous H2020 SW/HW Building Blocks in the frame of On-Orbit Servicing scenario.
- Recording of numerous datasets to characterize visual navigation solutions in visible & thermal spectrum
- **Demonstration of the rendezvous approach in autonomous closed-loop with a visual navigation chain**
- Demonstration of the autonomy to handle nominal and contingency scenarios in case of failure



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- Integration of previous H2020 SW/HW Building Blocks in the frame of On-Orbit Servicing scenario.
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- Demonstration of the rendezvous approach in autonomous closed-loop with a visual navigation chain
- **Demonstration of the autonomy to handle nominal and contingency scenarios in case of failure**

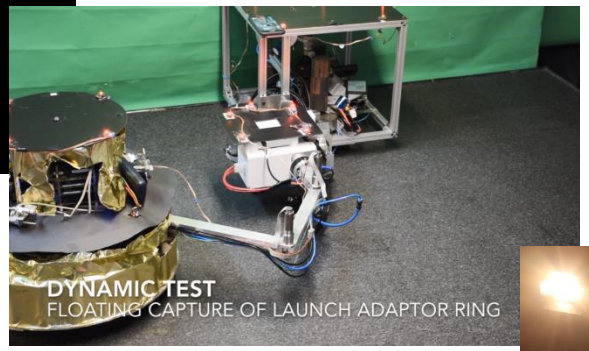
NOMINAL SCENARIO : 36m -> 2m

CONTINGENCY SCENARIO : 36m -> 20m

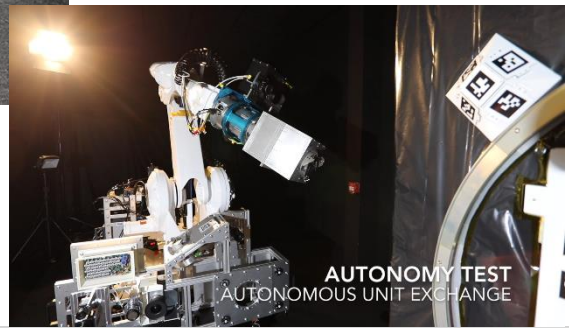
EROSS Experimental Results

❑ Test Campaign Overview

Approach and Rendezvous by GNC
& Vision-Based Navigation Validation
[Platform-Art, @GMV, April 2021]



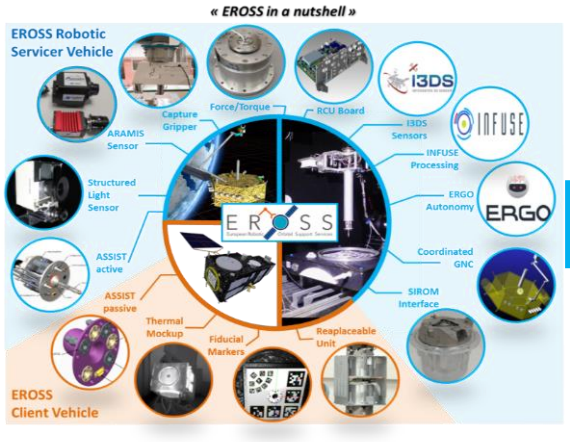
Robotic Capture by Coordinated
Platform/Robot Controller Validation
[SRE bench, @NTUA, May 2021]



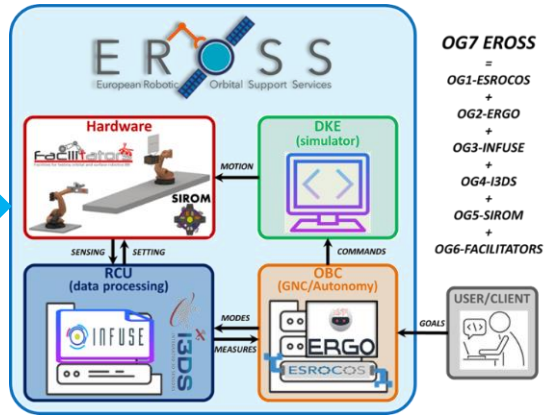
Orbital Unit Exchange
by Autonomous Task Planning
[ROBY bench, @TASF, June 2021]

EROSS Next Steps

- How to move from a set of BUILDING BLOCKS to a harmonized SOLUTION…
- …and to an IN-ORBIT DEMONSTRATION !

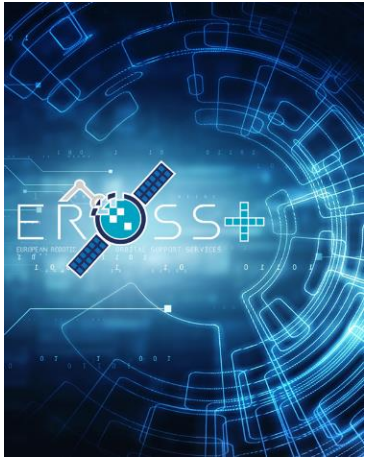


EROSS



OG7 EROSS
=
OG1-ESROCOS
+
OG2-ERGO
+
OG3-INFUSE
+
OG4-I3DS
+
OG5-SIROM
+
OG6-FACILITATORS

EROSS+



H2020 OG12 – EROSS+

(EUROPEAN ROBOTIC ORBITAL SUPPORT SERVICES)

PHASE A/B1 TOWARDS AN IN-ORBIT DEMONSTRATION OF KEY RENDEZVOUS AND ROBOTIC TECHNOLOGIES FOR ON-ORBIT SERVICES

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

GMV INNOVATING SOLUTIONS

PIAP SPACE

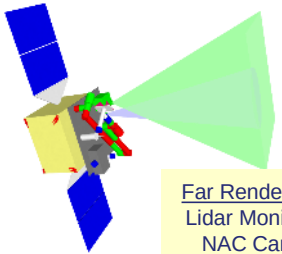
SINTEF

ThalesAlenia Space a Thales / Leonardo company

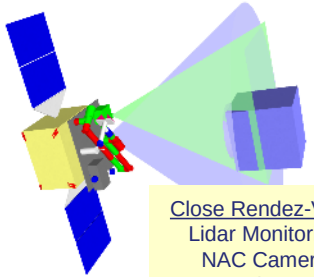
This project has received funding from the European Union's H2020 research and innovation programme under grant agreement No 101004346.

EROSS+ MISSION DESCRIPTION

Rendez-Vous

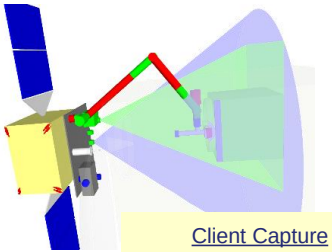


Far Rendez-Vous
Lidar Monitoring
NAC Camera
Arm Stowed

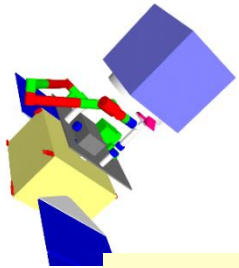


Close Rendez-Vous
Lidar Monitoring
NAC Camera
Arm Stowed

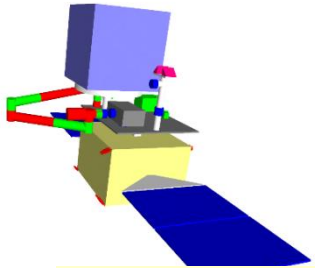
Servicing of Client



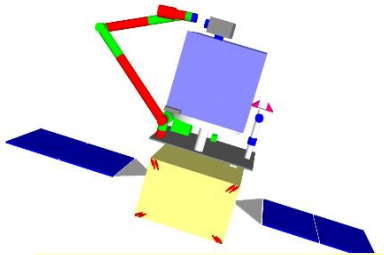
Client Capture
Relative sensor not used
Robotic arm deployed
Robotic Camera
Robotic Gripper



Client Mating
Relative sensors not used
Robotic arm release
Mating interface locking



Refuelling of Client
Inertial sensors/actuators for composite Servicer+Client
Robotic arm release & storage



Client Reconfiguration
Inertial sensors/actuators
Robotic arm coordinated control
Robotic Camera
Standard Interfaces

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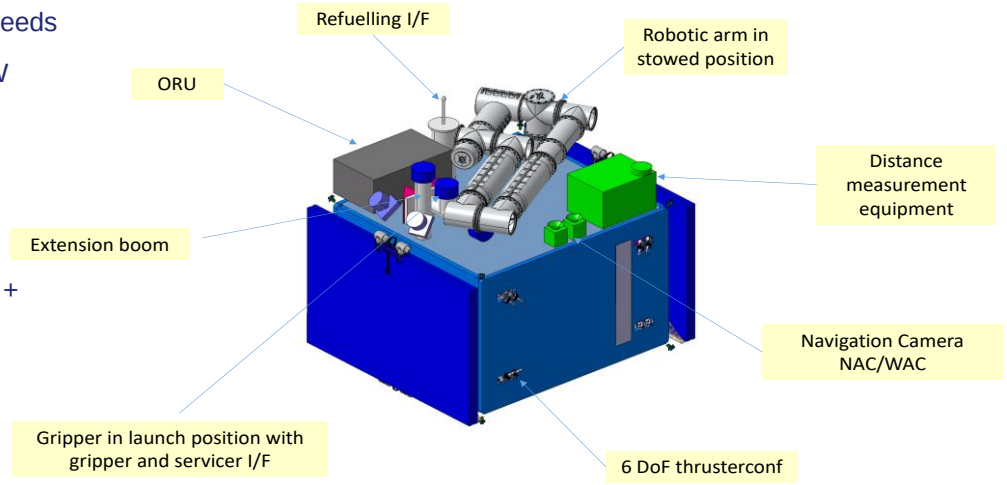
EROSS+ SERVICER CONCEPT

/// Modular design btw Platform & Rendezvous / Robotic Payload

- Parallel development to match tight planning of EROSS In Orbit Demonstration
- Anticipate transition to Commercial service with specific servicing needs
- Segregation of Platform mission critical SW from demonstration SW

/// Rendezvous / Robotic Payload

- Optical navigation cameras S-WAC / S-NAC
- Distance measurement equipment for monitoring (LIDAR)
- Robotic Arm : 7 joints with compliance control + Standard interface + camera
- Robotic Tool : Gripper with 2 standard interface for LAR grasping
- Standard interface for berthing capture client
- Refuelling interface for refuelling client
- Orbital Replaceable Unit (ORU) with 2 standard interfaces
- Dedicated computer “Servicing Control Unit” (SCU) to support Rendezvous vision and Robotic SW, and to implement their equipment interfaces



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AVIONICS: MAIN COMPONENTS

High Processing Capability Chip
(Zynq 7100 SoC Dual Core Arm A9)

Compact (<4kg) and configurable thanks its high number of communication links

/// Modular RTU:

- Decentralised approach thanks to **µRTU use called BoMo**.
- Very Low Cost Equipment

/// Modular DHS Architecture:

- Enable a high flexibility in the µRTU allocation in case Servicing Techno Development Components need more interfaces.
- I/Os budget done for identifying the number of BoMo and the dedicated lines to add for equipment management.

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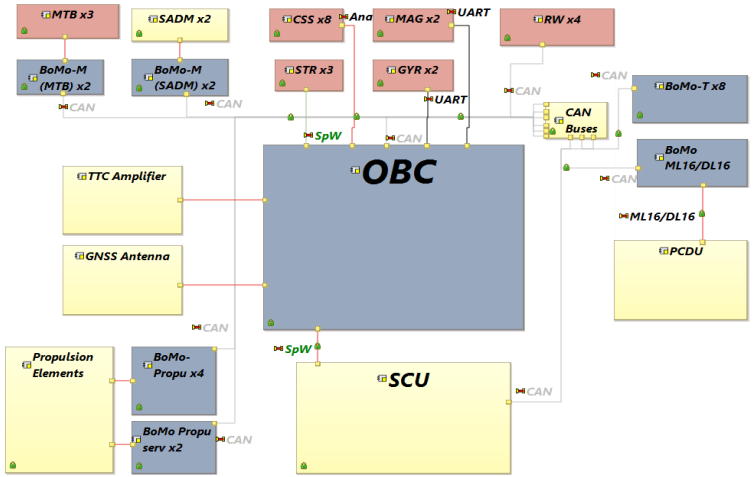
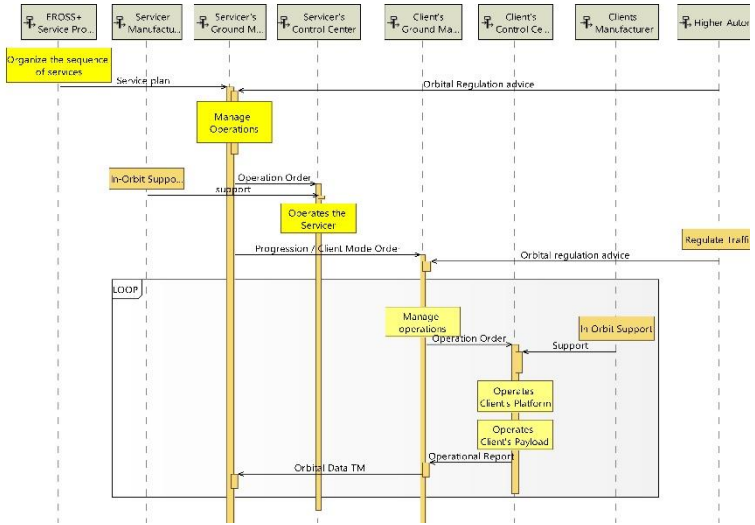
AVIONICS: WORKFLOW

/// Avionics Architecture matured for Mission (towards PhaseB2/C/D)

- => Instanciated for the demonstration in EROSS+ (phase B1)
- => Generation of scenario execution with interfaces constraints
- => Maintenance of the Capella model for the next phase B2/C/D





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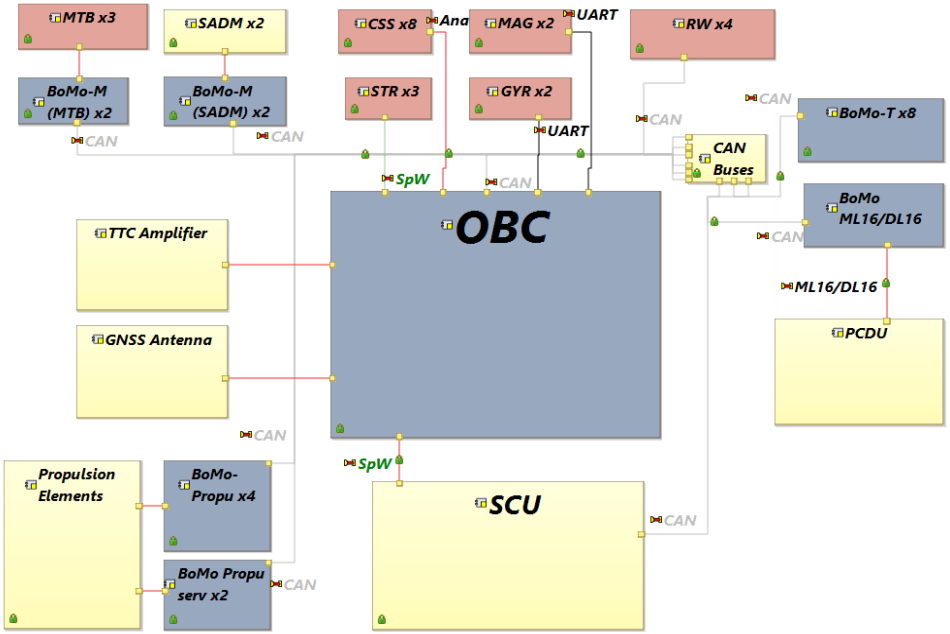
AVIONICS: DESIGN

/// Platform Avionics Architecture

- AOCS equipment with red blocks
- DHS equipment with blue blocks

/// **Platform and Servicing Payload coupling by OBC⇔SCU link**



/// Main AOCS and DHS components are already developed and tested on a test bench in a **flat sat configuration following an Agile development**

/// Main communications with equipment through 3 CAN bus

/// High TRL and low cost platform enables to make highest efforts on the Servicing Payload development.

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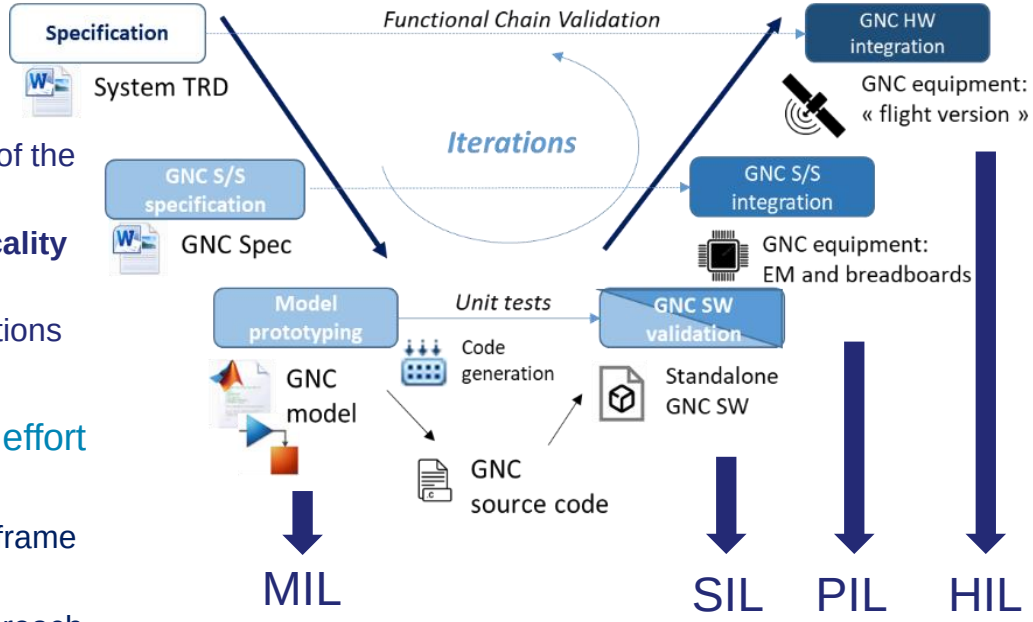
ON-BOARD SOFTWARE: GNC WORKFLOW

/// IVV process adapted to cope with stringent programmatic milestones

- Validation effort split in **multiple iterations**.
- Each iteration correspond to a high level **need/operational phase/design** feature.
- Each iteration consists of an end-to-end repetition of the **V-cycle**.
- The iterations are organized according to the **criticality of the feature** under evaluation.
- **Same tools** used consistently across several iterations (incremental process).

/// Capitalization of development and validation effort of previous R&D studies

- Many features of GNC SW already covered in the frame of “H2020 OG7 – EROSS” up to MIL/SIL validation
- On-going activities in “H2020 OG12 - EROSS+” to reach PIL/HIL level on a representative OBC/SCU



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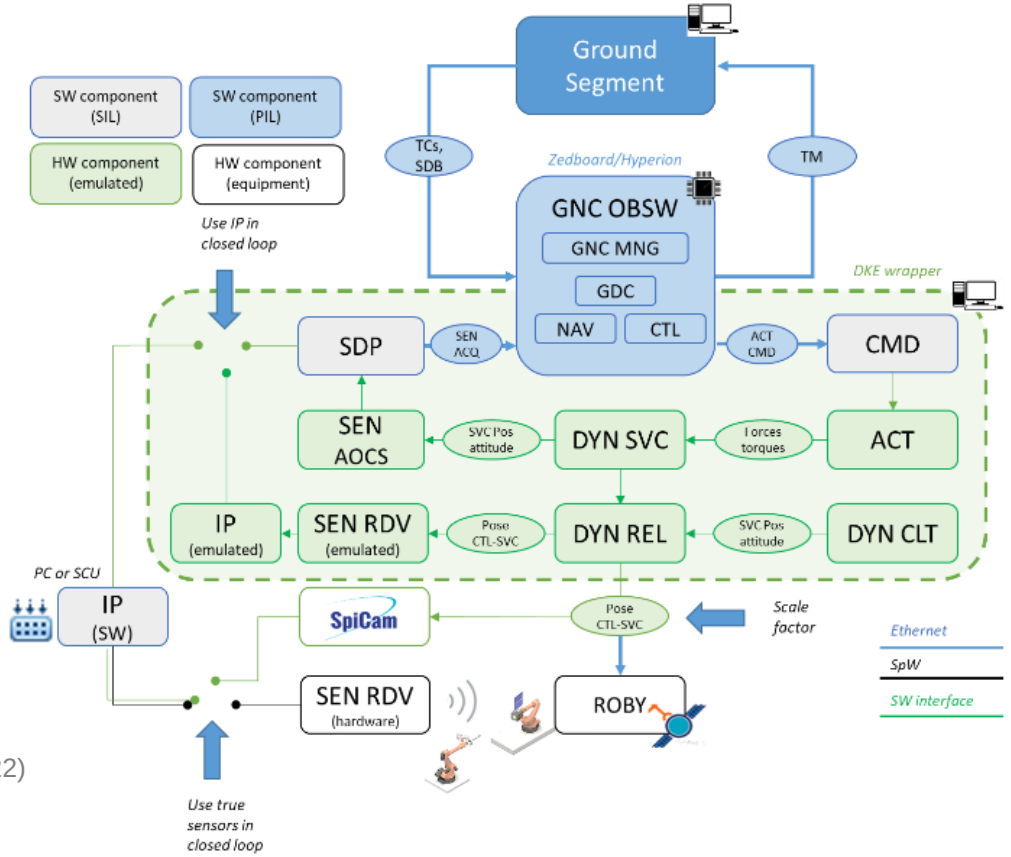
ON-BOARD SOFTWARE: GNC VALIDATION

/// Avionics test bench

- OBC with representative Flight Operating System
- EGSE with
  - Dynamics, Kinematics, Environment (DKE)
  - Image Generation : SPICAM Generator (by TASF)
  - Image Processing : C++ code (before SCU implementation)

/// Validation Perimeter

- Cruise and stand-by (conventional AOCS)
  - AOCS equipment modeled (not procured yet)
  - ✓ Preliminary derisking/validation up to SIL
  - ✓ Final PIL/HIL to be completed in avionics test bench
- Long-range rendez-vous
  - PIL/HIL tests in the frame of EROSS+
  - ✓ PIL/HIL validation of SNAC/SWAC image processing
  - ✓ Final PIL/HIL to be performed on robotic test bench (Q4-2022)



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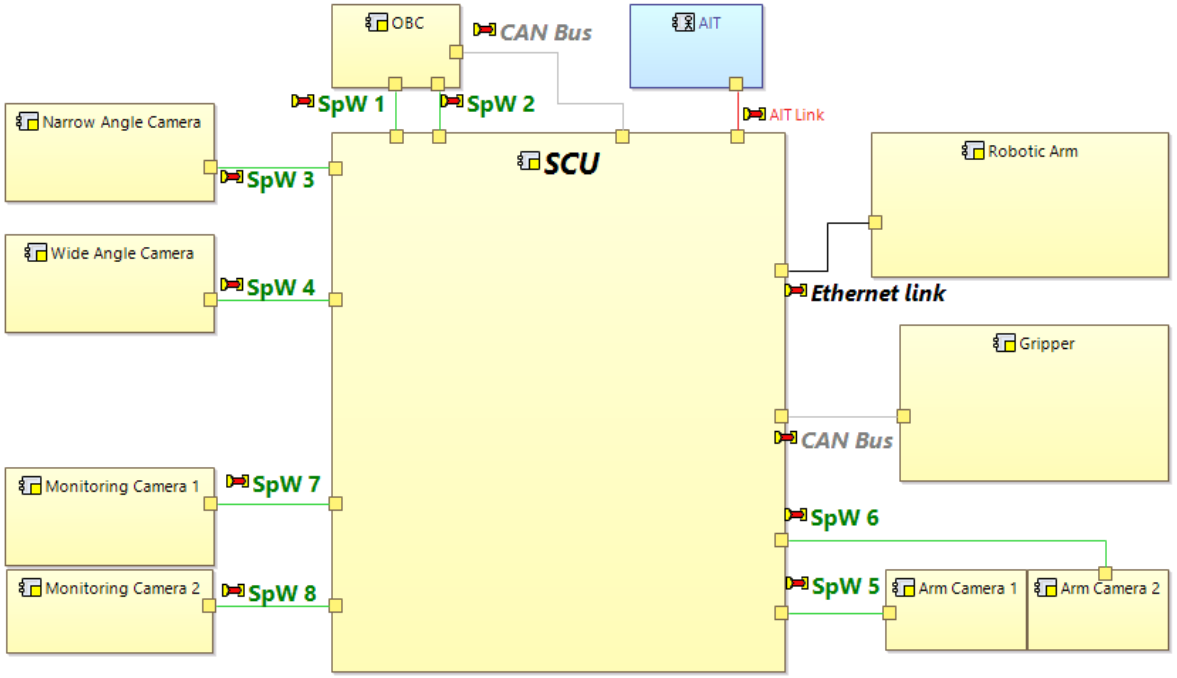
AVIONICS: SERVICING CONTROL UNIT (SCU) / HW

/// The **S**ervicing **C**ontrol **U**nit **– SCU** manages all the Servicing Units (RendezVous and Robotics)
*(previously named **R**obotic **C**ontrol **U**nit - **RCU**)*

HW

Equipment to Interface:

- Robotic Arm
- Gripper
- Robotic Camera
- Monitoring Cameras
- Narrow Angle Camera
- Wide Angle Camera
- Distance Measurement Unit
- On-Board Computer



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AVIONICS: SERVICING CONTROL UNIT (SCU) / SW

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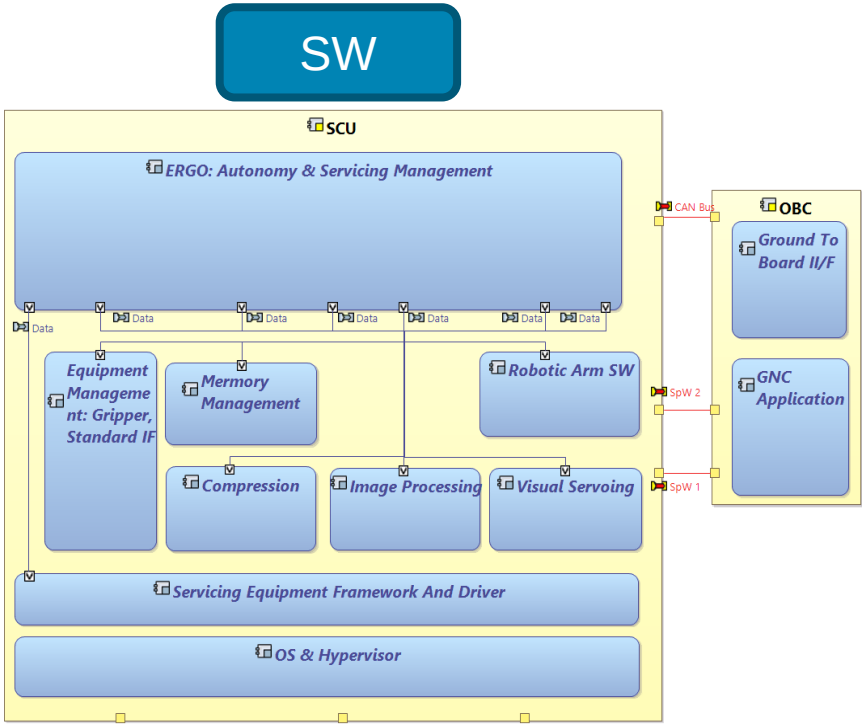

SW Components to embed:

- Rendezvous - Image Processing SW
- Robotic - Arm Controller & Skill Engine
- Robotic - ERGO autonomous agent (Servicing Planner)
- Robotic - Image Processing SW
- Common - I3DS Equipment Layer and the management of other equipment: Standard Interface, Gripper, etc…
- Common - Image Compression
- Common - Mass Memory Management

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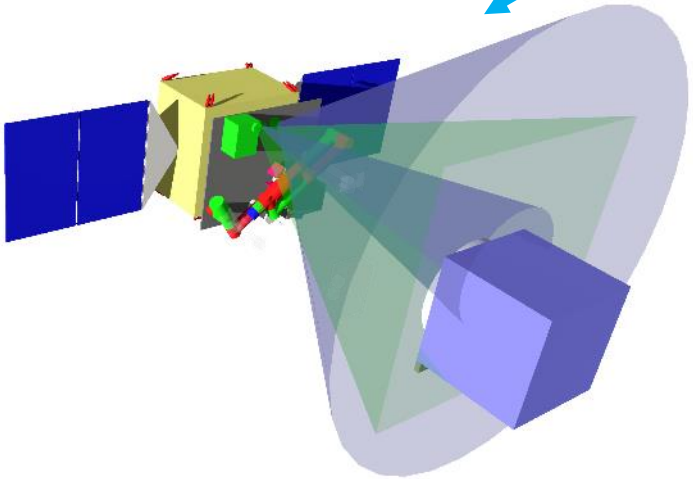
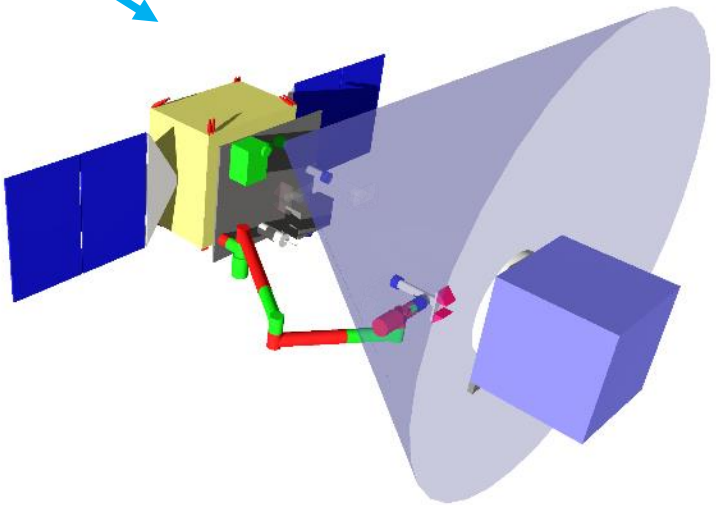
KEY TECHNOLOGIES: OVERVIEW

/// **Critical Technologies** Identification & Maturation Plan

/ Vocabulary: **Rendezvous** VS **Servicing**



From 2km to 2m
(approach, fly-around, forced motion)



From 2m to Contact & Berthing
(capture, berthing, unit exchange)

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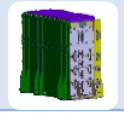
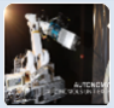
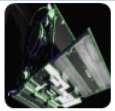
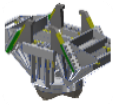
KEY TECHNOLOGIES: STATUS

Hardware Technologies (blue),
Software Technologies (purple),
Validation Technologies (green).

/// **Critical Technologies** Identification & Maturation Plan

Application	Image	Key Technology	TRL Current	TRL Target
Rendezvous & Servicing		**TechDev#1 :** [HW] Servicing Control Unit (interfaces and processing needs)	TRL 4	TRL 6
Rendezvous & Servicing		**TechDev#2 :** [SW] I3DS Equipment Layer software (Sensors & Actuators)	TRL 4	TRL 5
Rendezvous & Servicing		**TechDev#3 :** [HW] AvionicsTest Bench for Rendezvous & Servicing operations	N/A	N/A
Rendezvous		**TechDev#4 :** [SW] Rendezvous Image Processing algorithms	TRL 5	TRL 5
Rendezvous		**TechDev#5 :** [SW] Rendezvous GNC algorithms	TRL 4	TRL 5
Rendezvous		**TechDev#6 :** [HW] Validation Test Bench for Visual Navigation for rendezvous	N/A	N/A

Application	Image	Key Technology	TRL Current	TRL Target
Servicing		**TechDev#7 :** [HW] Robotic Arm development	TRL 5	TRL 5+
Servicing		**TechDev#8 :**[HW] Robotic Gripper dev. & qualification (mechanisms & electronics)	TRL 3	TRL 6
Servicing		**TechDev#9 :** [SW] Robotic Image Processing algorithms	TRL 4	TRL 5
Servicing		**TechDev#10 :** [SW] Robotic Controller & Skill Engine algorithms for capture and servicing	TRL 5	TRL 5+
Servicing		**TechDev#11 :** [SW] Robotic Autonomy software for servicing operations	TRL 4	TRL 5
Servicing		**TechDev#12 :** [HW] Validation Test Bench for Robotic Operations for capture / servicing	N/A	N/A

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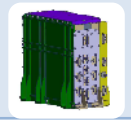
KEY TECHNOLOGIES: STATUS

Hardware Technologies (blue), Technologies (purple), Technologies (green).

SLIDE SOURCE AVEC TEXTE

/// Critical Technologies identification & Maturation Plan

Application	Image	Key Technology	TRL Current	TRL Target
Rendezvous & Servicing		**TechDev#1 :** [HW] Servicing Control Unit (interfaces and processing needs)	TRL 4	TRL 6
Rendezvous & Servicing	I3DS	**TechDev#2 :** [SW] I3DS Equipment Layer software (Sensors & Actuators)	TRL 4	TRL 5
Rendezvous & Servicing		**TechDev#3 :** [HW] AvionicsTest Bench for Rendezvous & Servicing operations	N/A	N/A
Rendezvous		**TechDev#4 :** [SW] Rendezvous Image Processing algorithms	TRL 5	TRL 5
Rendezvous		**TechDev#5 :** [SW] Rendezvous GNC algorithms	TRL 4	TRL 5
Rendezvous		**TechDev#6 :** [HW] Validation Test Bench for Visual Navigation for rendezvous	N/A	N/A

Application	Image	Key Technology	TRL Current
Servicing		**TechDev#7 :** [HW] Robotic Arm development	TRL 5
Servicing		**TechDev#8 :**[HW] Robotic Gripper dev. & qualification (mechanisms & electronics)	TRL 3
Servicing		**TechDev#9 :** [SW] Robotic Image Processing algorithms	TRL 4
Servicing		**TechDev#10 :** [SW] Robotic Controller & Skill Engine algorithms for capture and servicing	TRL 5
Servicing	ERGO	**TechDev#11 :** [SW] Robotic Autonomy software for servicing operations	TRL 4
Servicing		**TechDev#12 :** [HW] Validation Test Bench for Robotic Operations for capture / servicing	N/A

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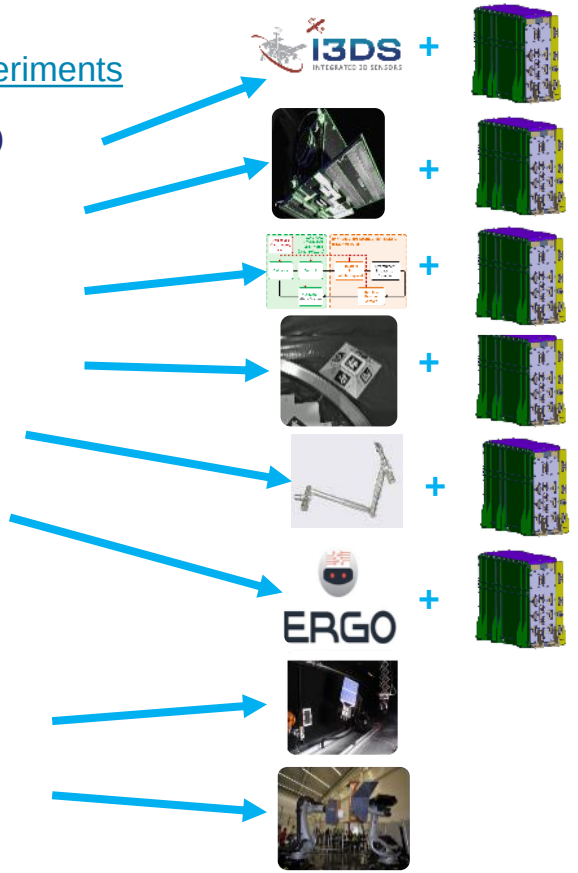
KEY TECHNOLOGIES: TESTS & EXPERIMENTS

/// “Derisking Activities” = intermediate cross-checks towards the experiments

- **Derisking Activity # 1** : I3DS SW porting on SCU (Equipment Layer Software)
- **Derisking Activity # 2** : Rendezvous Image Processing porting on SCU
- **Derisking Activity # 3** : Rendezvous G-N-C porting on OBC model
- **Derisking Activity # 4** : Robotic Image Processing porting on SCU
- **Derisking Activity # 5** : Robotic Controller & Skill Engine porting on SCU
- **Derisking Activity # 6** : Robotic Autonomy porting on SCU

/// “Experiments” = end-to-end validation of a functional chain/loop

- **Experiment #1 :** Autonomous Rendezvous Demonstration
  - Platform-Art bench @GMV, Nov. 2022.
- **Experiment #2 :** Autonomous Robotic Capture & Servicing Demonstration
  - CAESAR bench @DLR, Dec. 2022.



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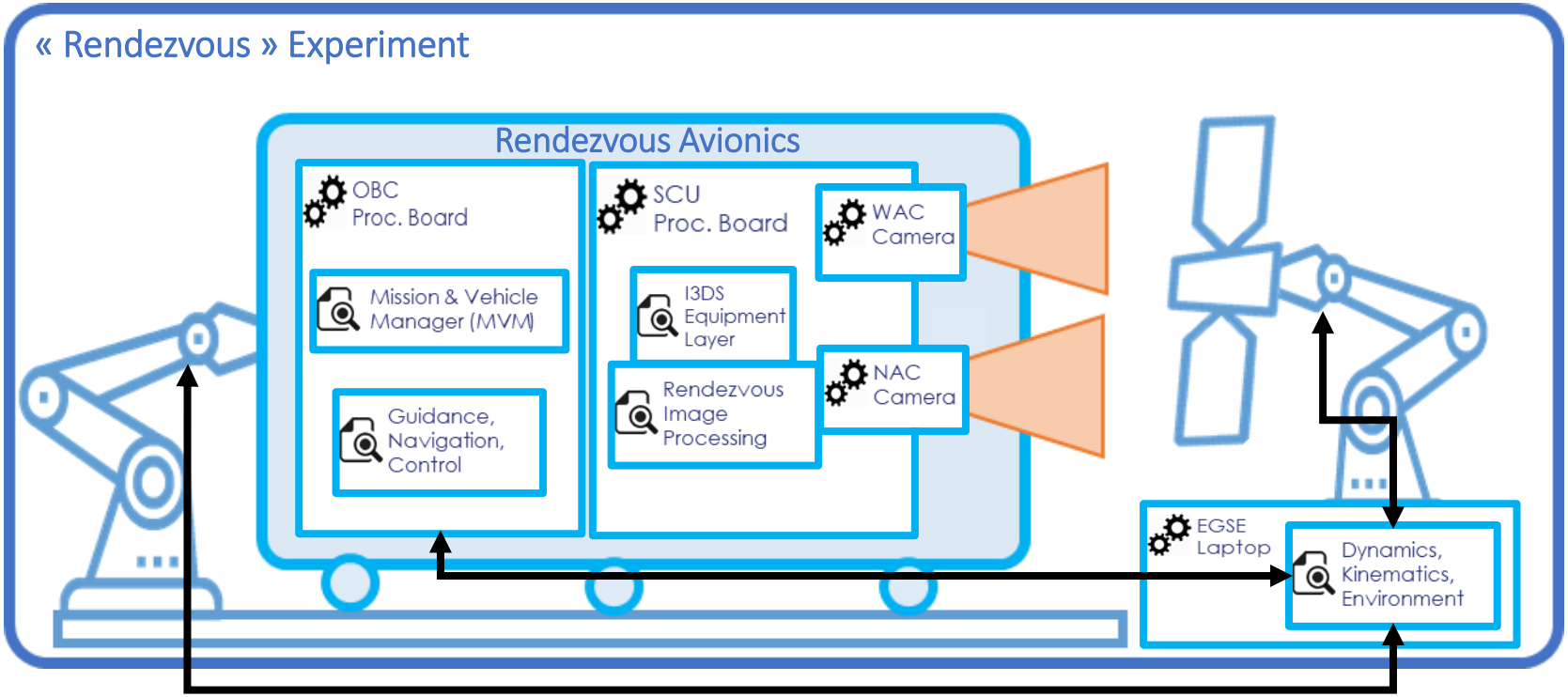
KEY TECHNOLOGIES: RENDEZVOUS EXPERIMENT

/// « Rendezvous Demonstration » : relative motion based on GNC & autonomy



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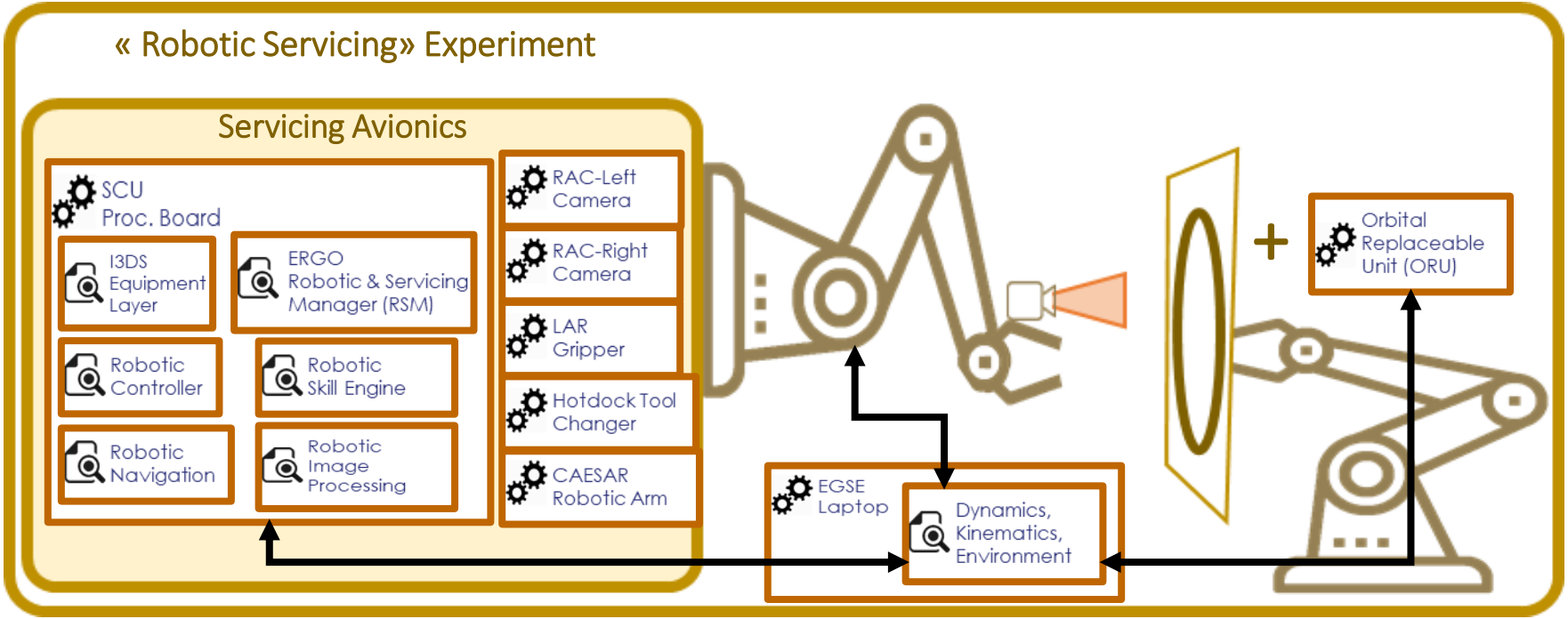
KEY TECHNOLOGIES: ROBOTIC SERVICING EXPERIMENT

/// « Robotic Demonstration » : from arm deployment to capture and client servicing



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EROSS+ NEXT STEPS

/// Phase B1 closure by January 2023

- Frozen Servicer design
- Consolidation of Validation Plan (DDVP)
- Consolidation of Planning & Cost towards flight demonstration

/// Derisking Activities for Key Technologies

- On-going porting of all SW on OBC & SCU units
- Rendezvous GNC & Vision SW
- Robotic Controller/Autonomy SW

/// End-to-End Experiments

- Validation of rendezvous technologies at GMV in Nov. 2022
- Validation of robotic technologies at DLR in Dec. 2022

/// … Horizon Europe project “EROSS IOD” (In-Orbit Demonstration) for a launch in 2026 !

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THANK YOU FOR YOUR ATTENTION !

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a Thales / Leonardo company

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