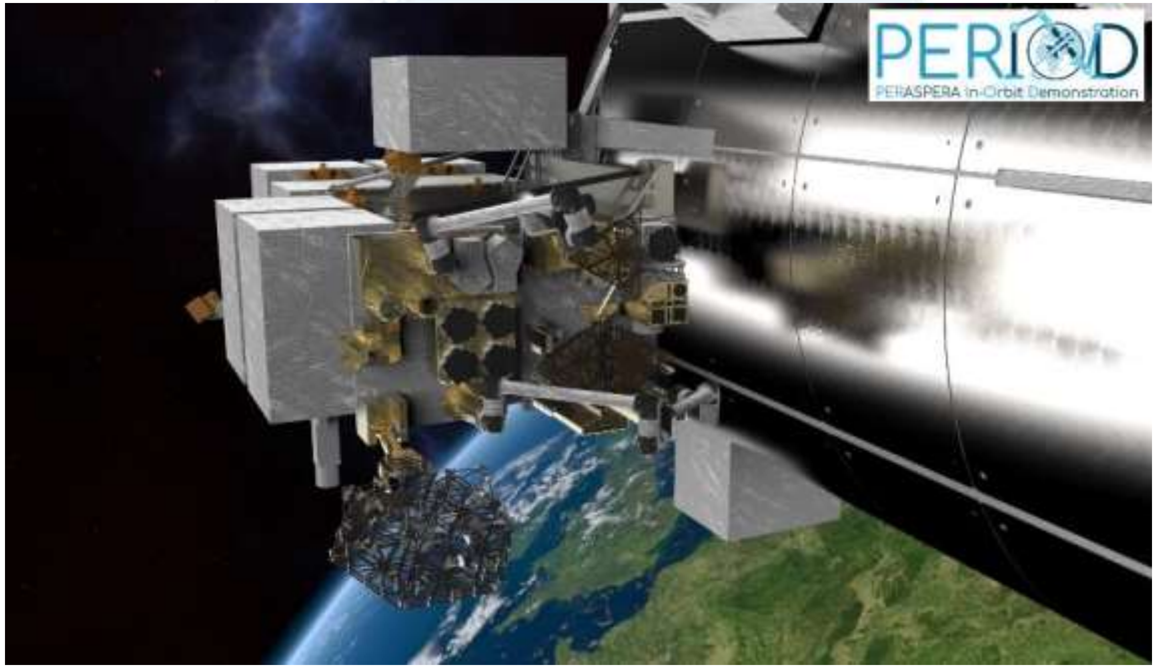
ROBOTIC ARCHITECTURE AND OPERATIONAL CONCEPT FOR IN-SPACE ASSEMBLY AND SERVICING MISSIONS

PERIOD – PERASPERA IN-ORBIT DEMONSTRATION



June 1, 2022

European Commission

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement No 101004151

Agenda

- Introduction & Motivation
- Mission Definition
- Operational Concept
- System Architecture
- Building Blocks

Consortium

AIRBUS

gmv INNOVATING SOLUTIONS

spaceapplications SERVICES

SENER Aeroespacial

DFKI German Research Center for Artificial Intelligence

ISISPACE

easn Technology Innovation Services

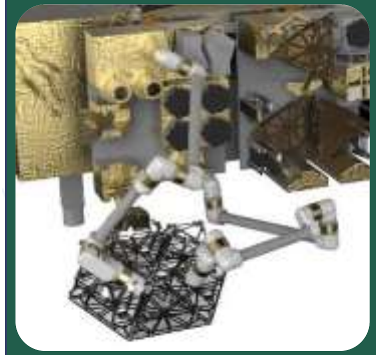
Introduction and Motivation

Develop a new ISMA and IOS business

Change the state of the space ecosystem to ‘Next Space’.

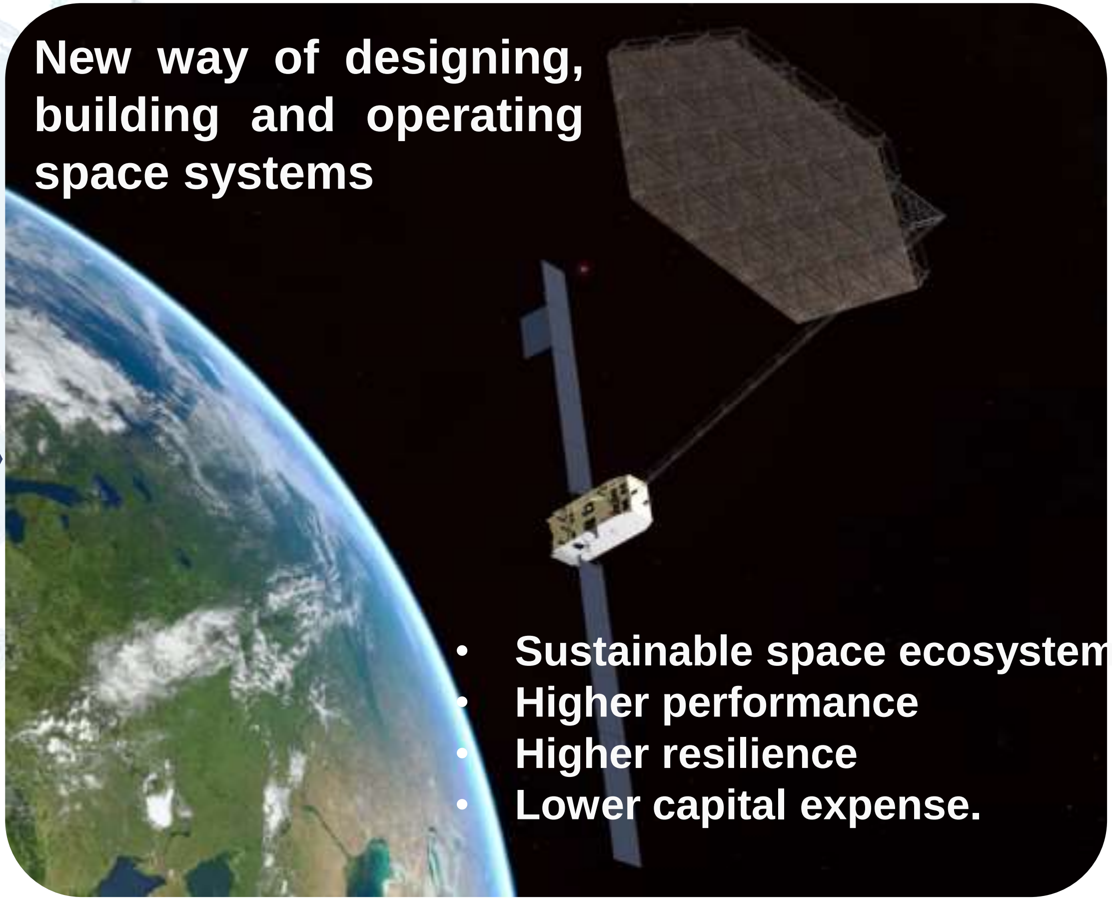
Problem

Current state



ISMA Capability

Solution



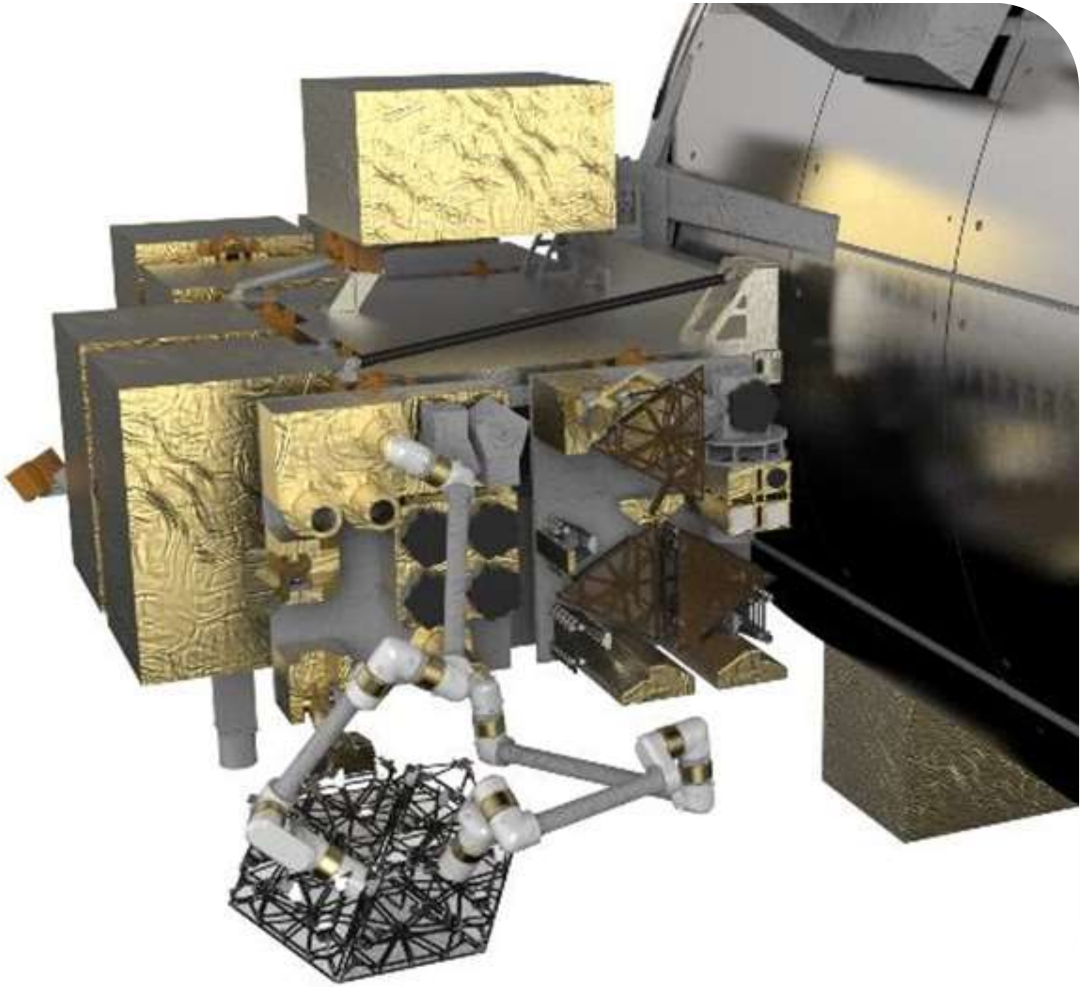
Next state

Technology push to new ISMA capabilities

Reliable and high performance robotic Common Building Blocks for operation in space environments from SRC.

Selected operations in space environment:

1. Assembly of antenna reflector.
2. Assembly of complete satellite from building blocks equipped with SI including verification.
3. Reconfiguration of the satellite payload for system upgrade.
4. Inspection of the assembled satellite.
5. Refuelling with attachment.

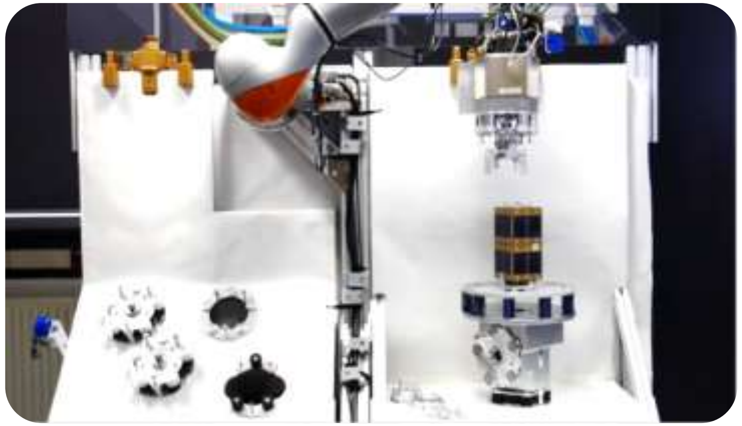


ISMA capabilities and SRC technologies selected to demonstrate the operations.

Technology push to new ISMA capabilities

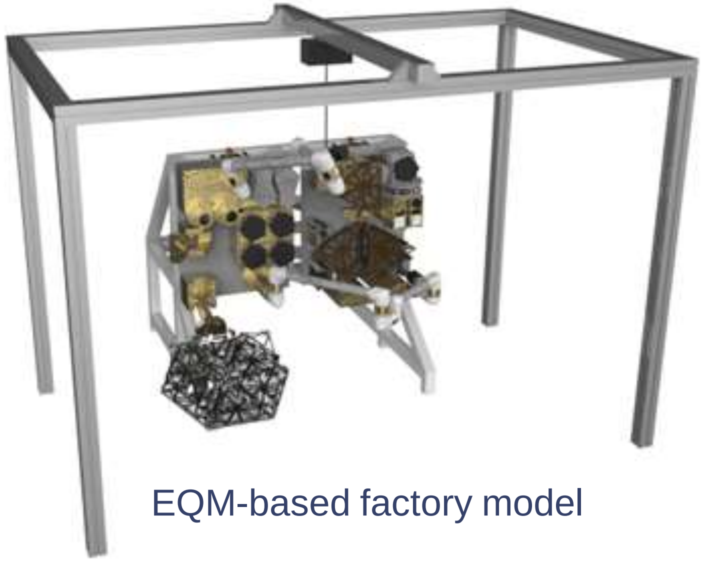
Incremental development from the ADS labs to an EQM-based factory model and to the In-Orbit Demonstration.

TRL 5



PERIOD Phase A/B1
System study,
technology development and
breadboarding
(2021-2022)

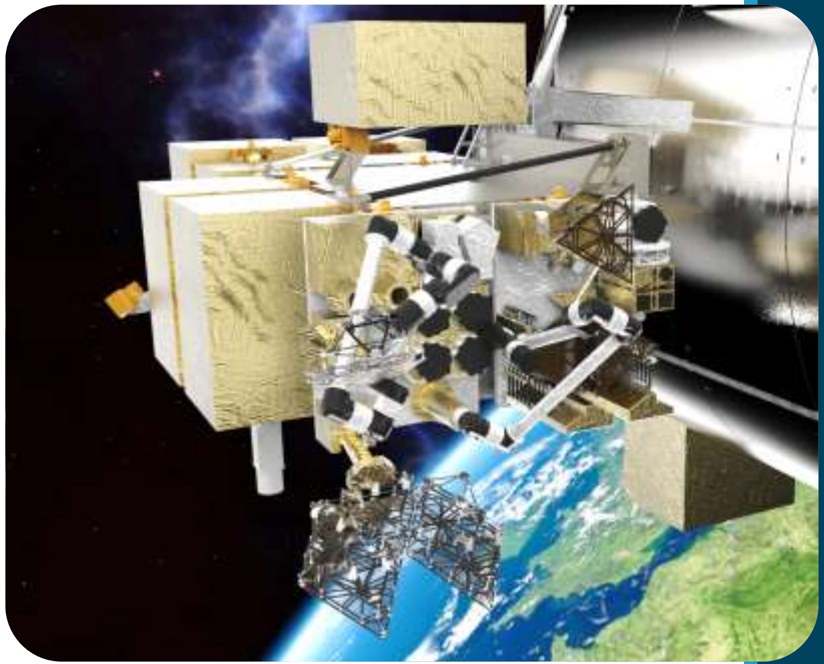
TRL 6



EQM-based factory model

PERIOD Phase B2/C
(2023-2025)

TRL 8



PERIOD Phase D/E
(2025-2026)

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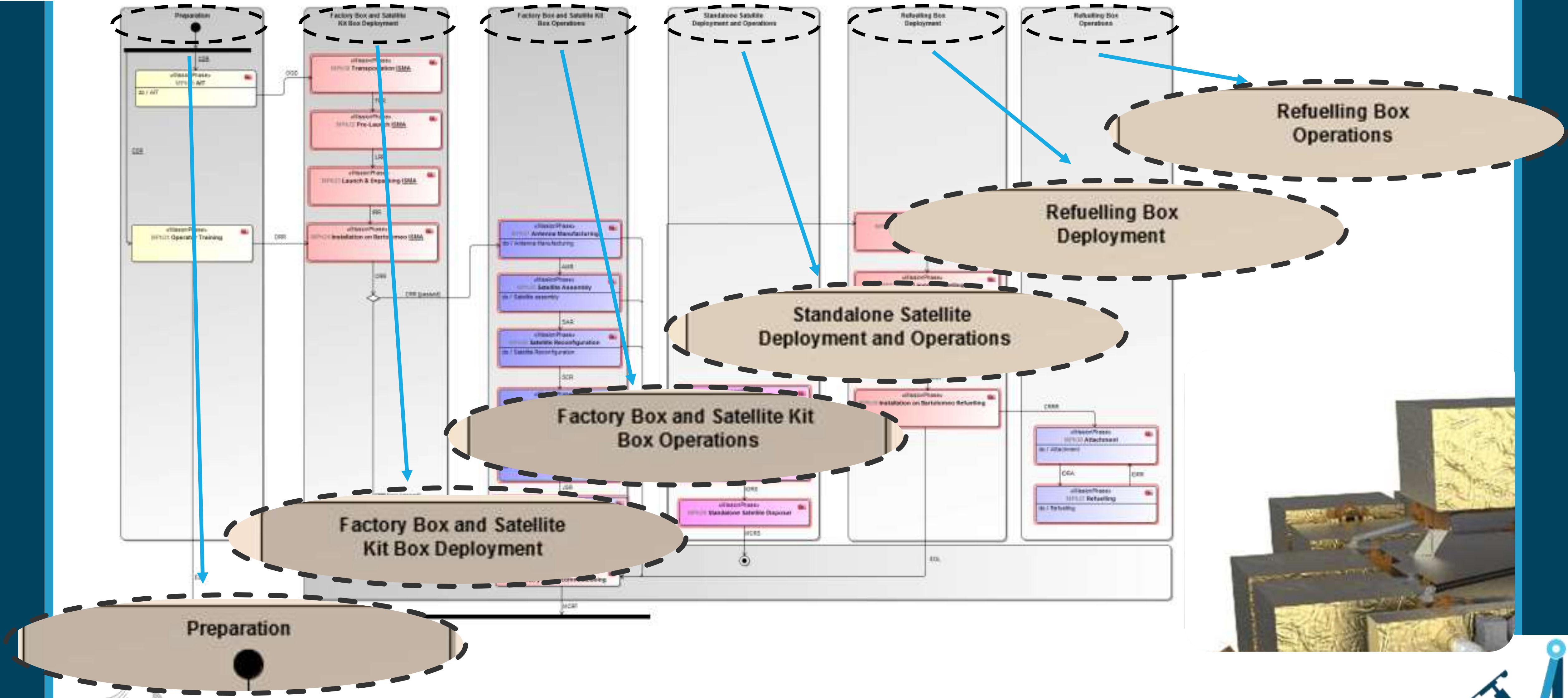
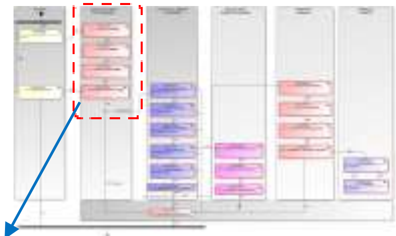
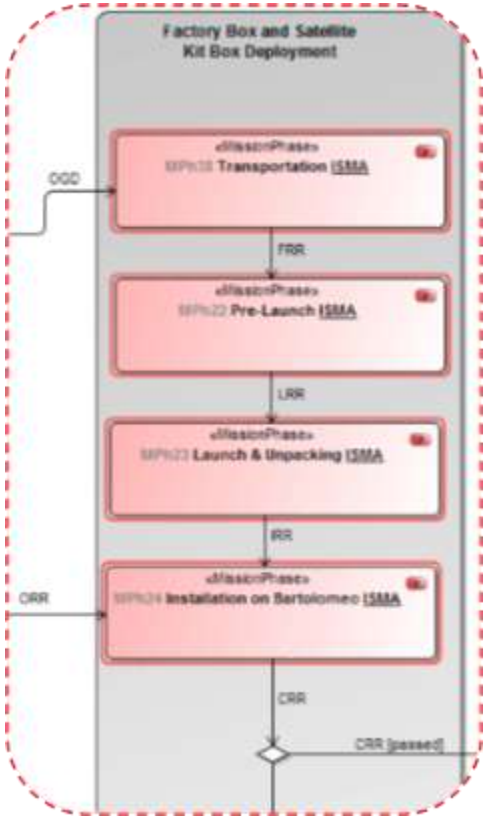
Mission Definition

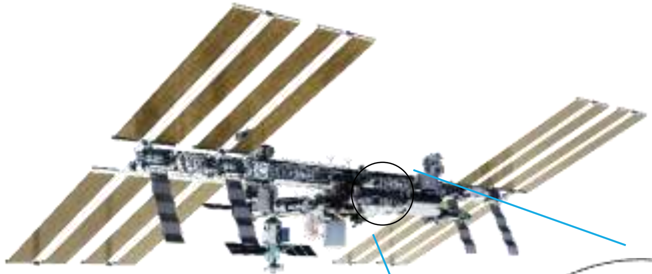
Mission overview with all phases

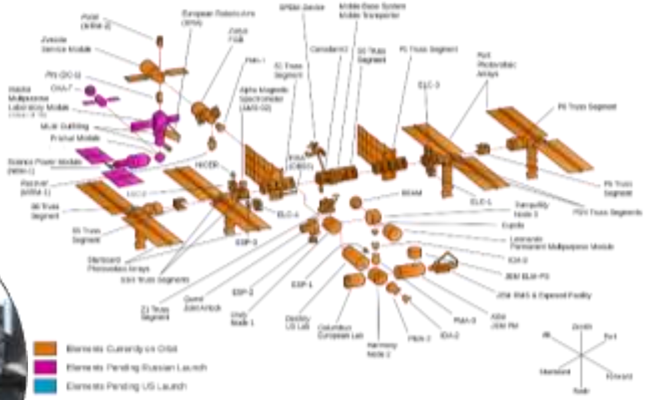


Factory Box and Satellite Kit Box Deployment



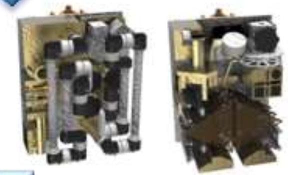




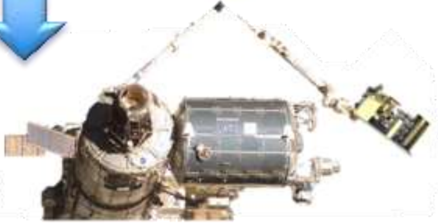


Boxes Soft Launch

Boxes Unpacking
Performed inside the ISS



Installation on
Bartolomeo
with MSS (Canadarm2)



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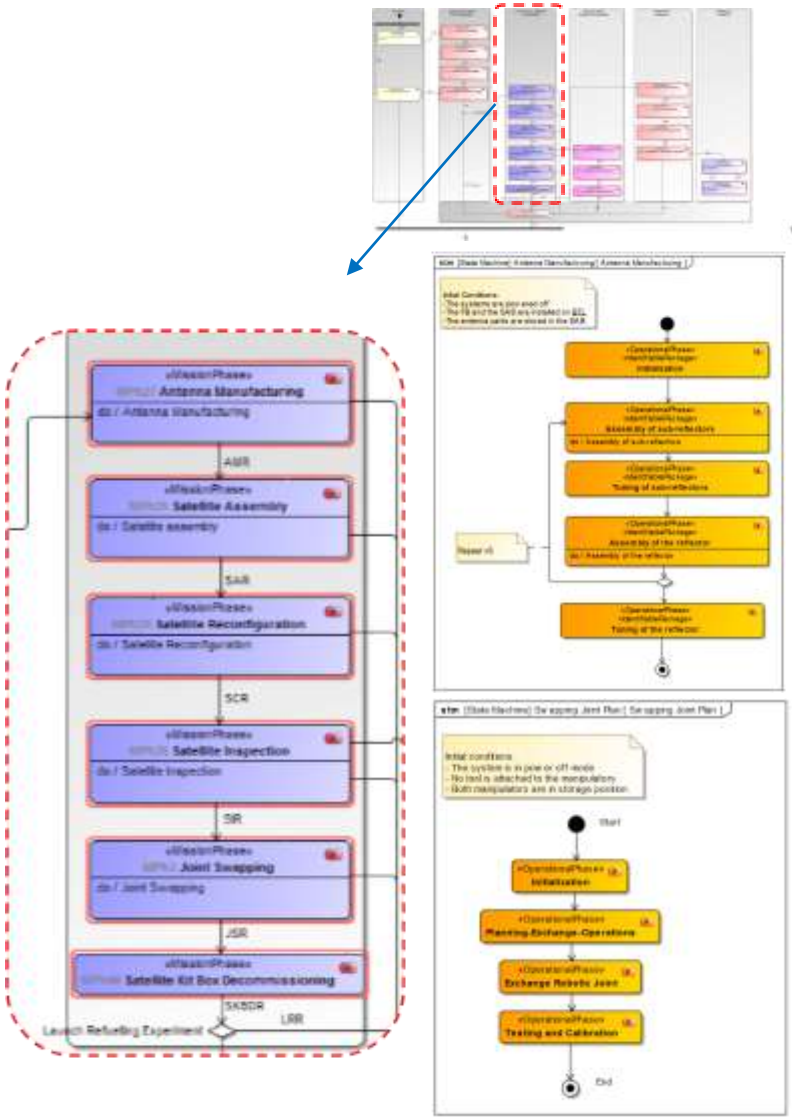
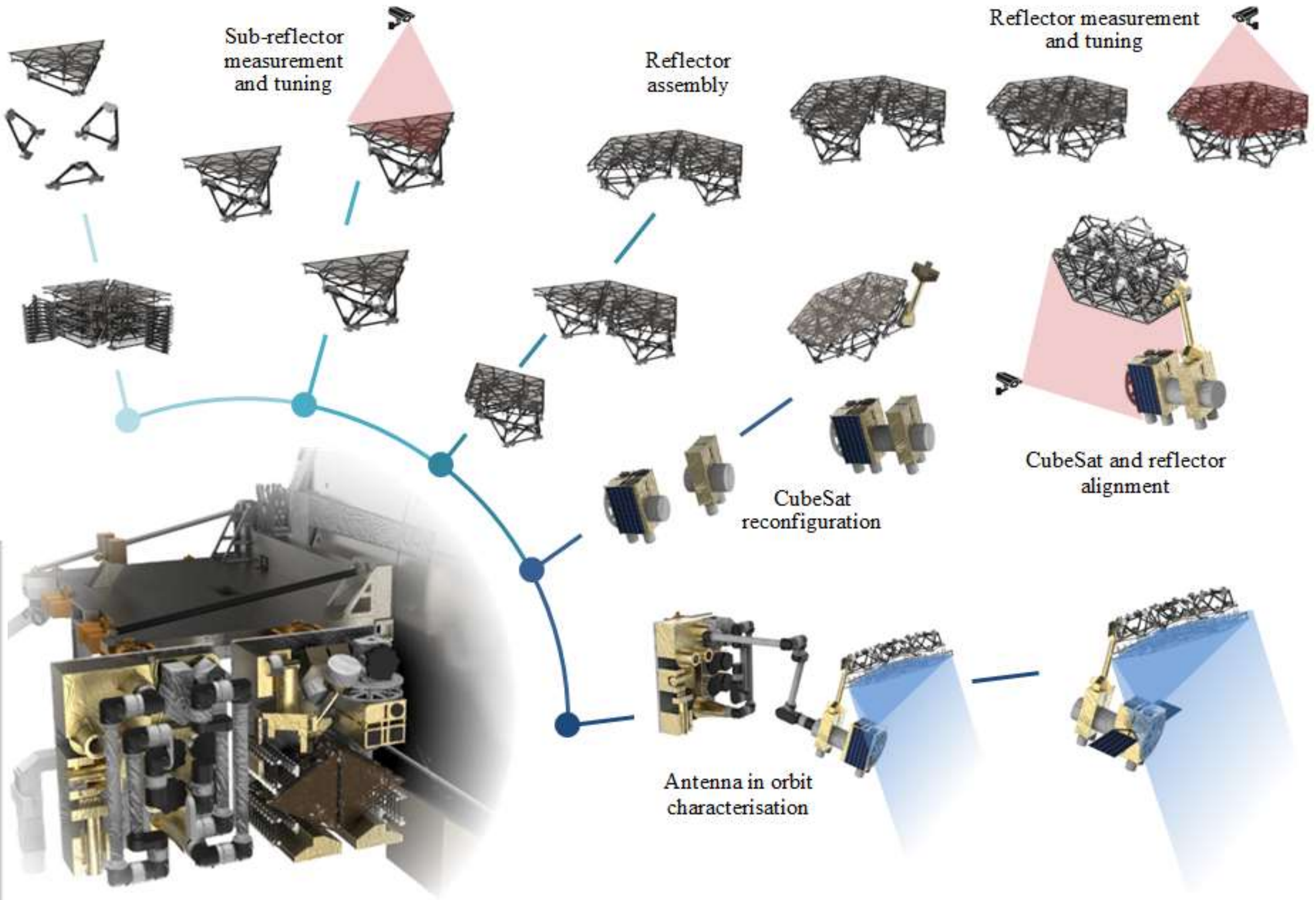
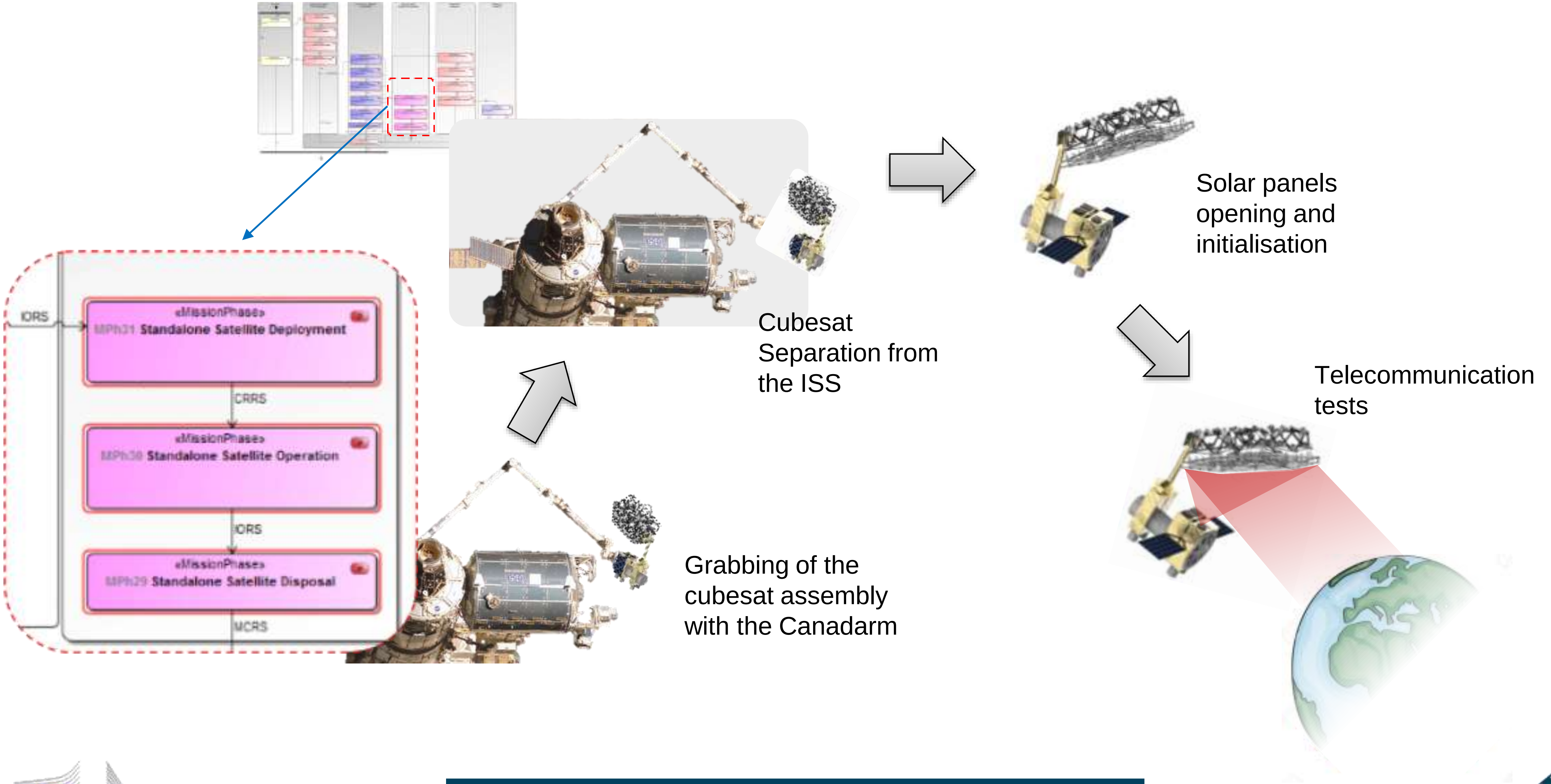
Factory Box and Satellite Kit Box Operations





Standalone Satellite Deployment and Operations



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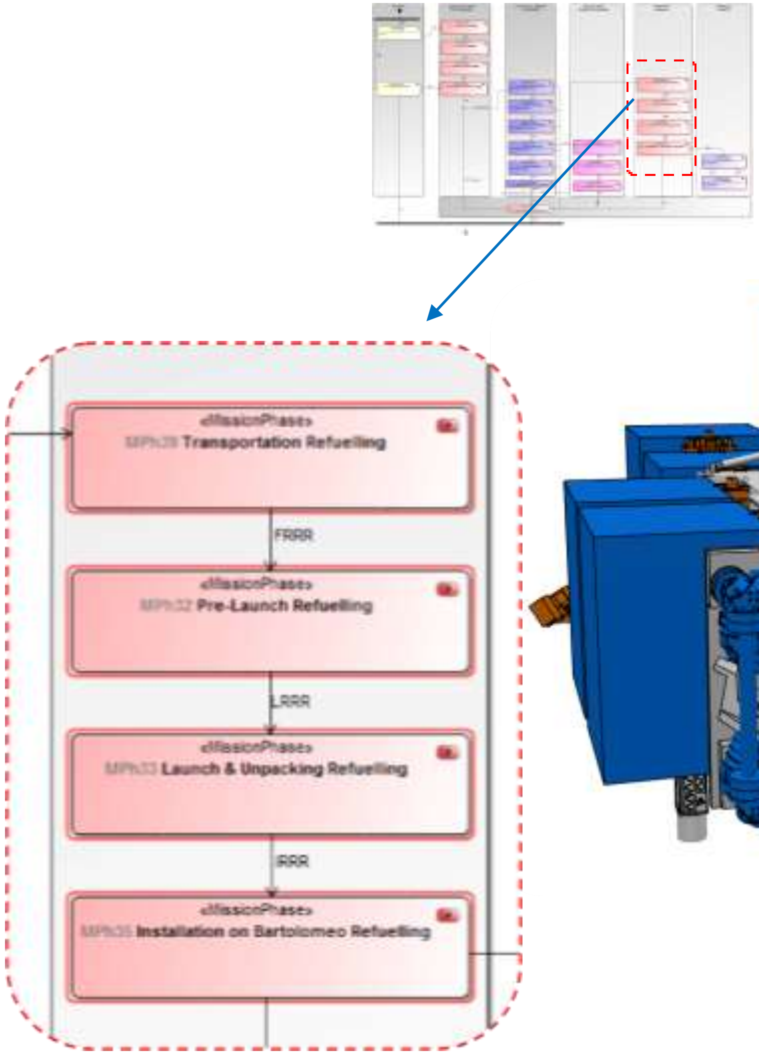
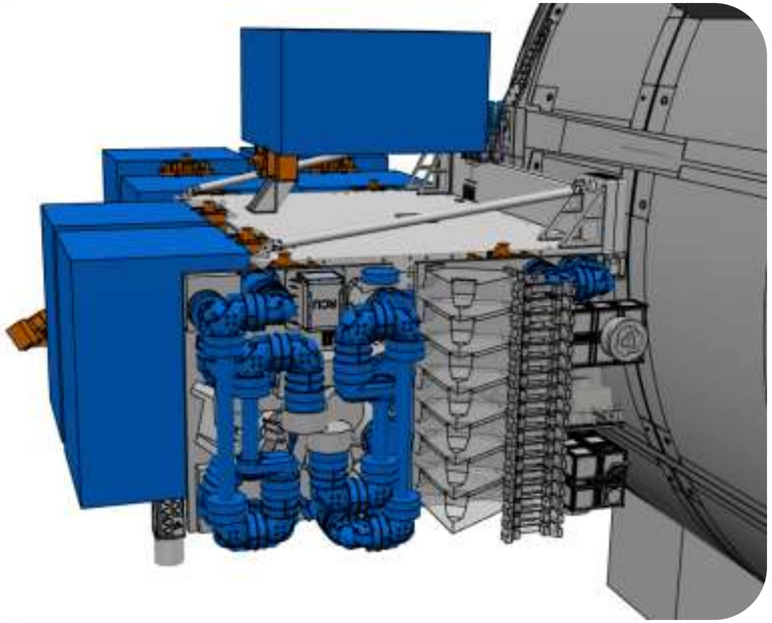
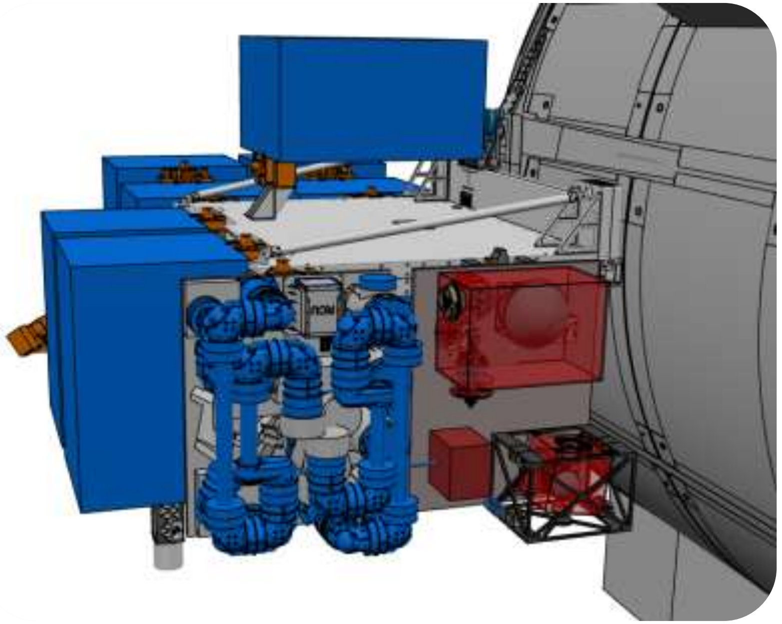
Refueling Box Deployment



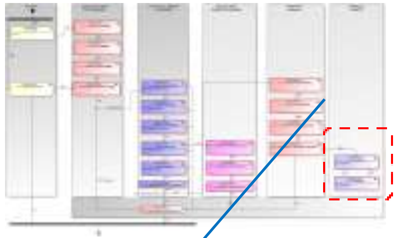


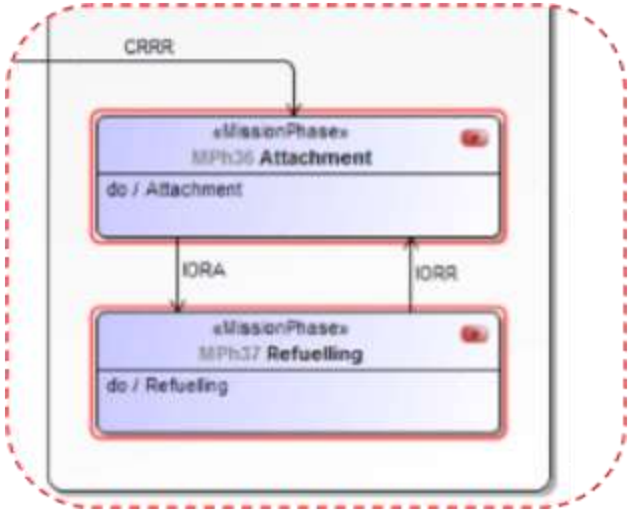
Satellite kit box configuration



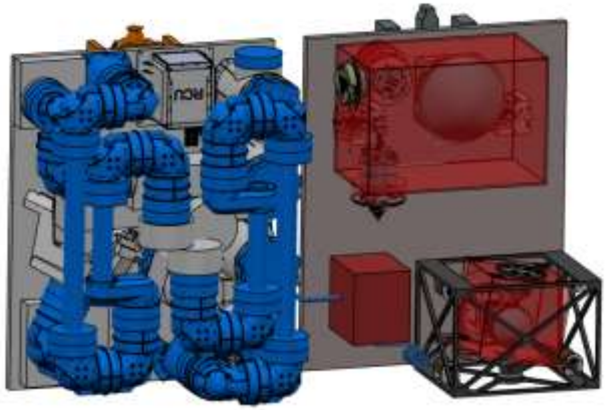
Refuelling box configuration

Refueling Box Operations

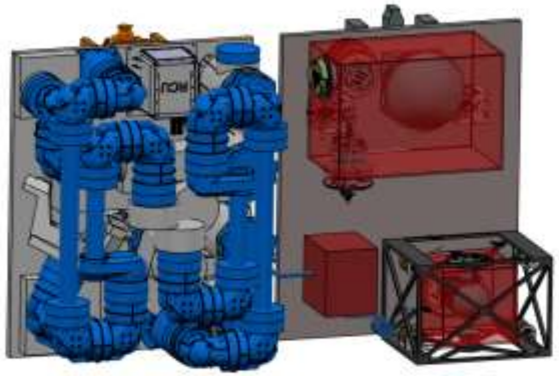




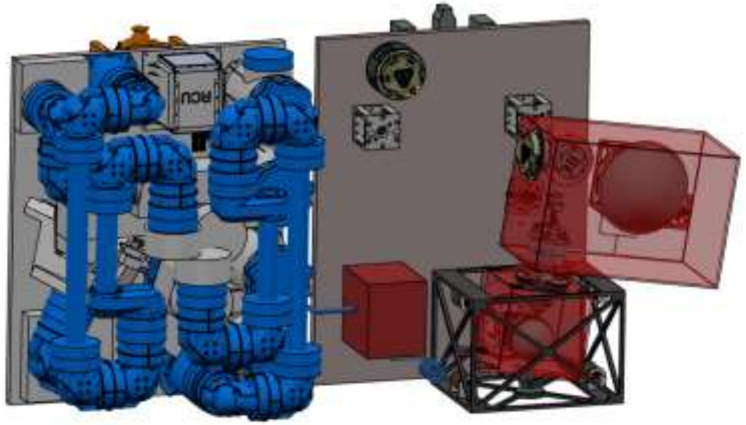
Floating client target configuration



Initial configuration

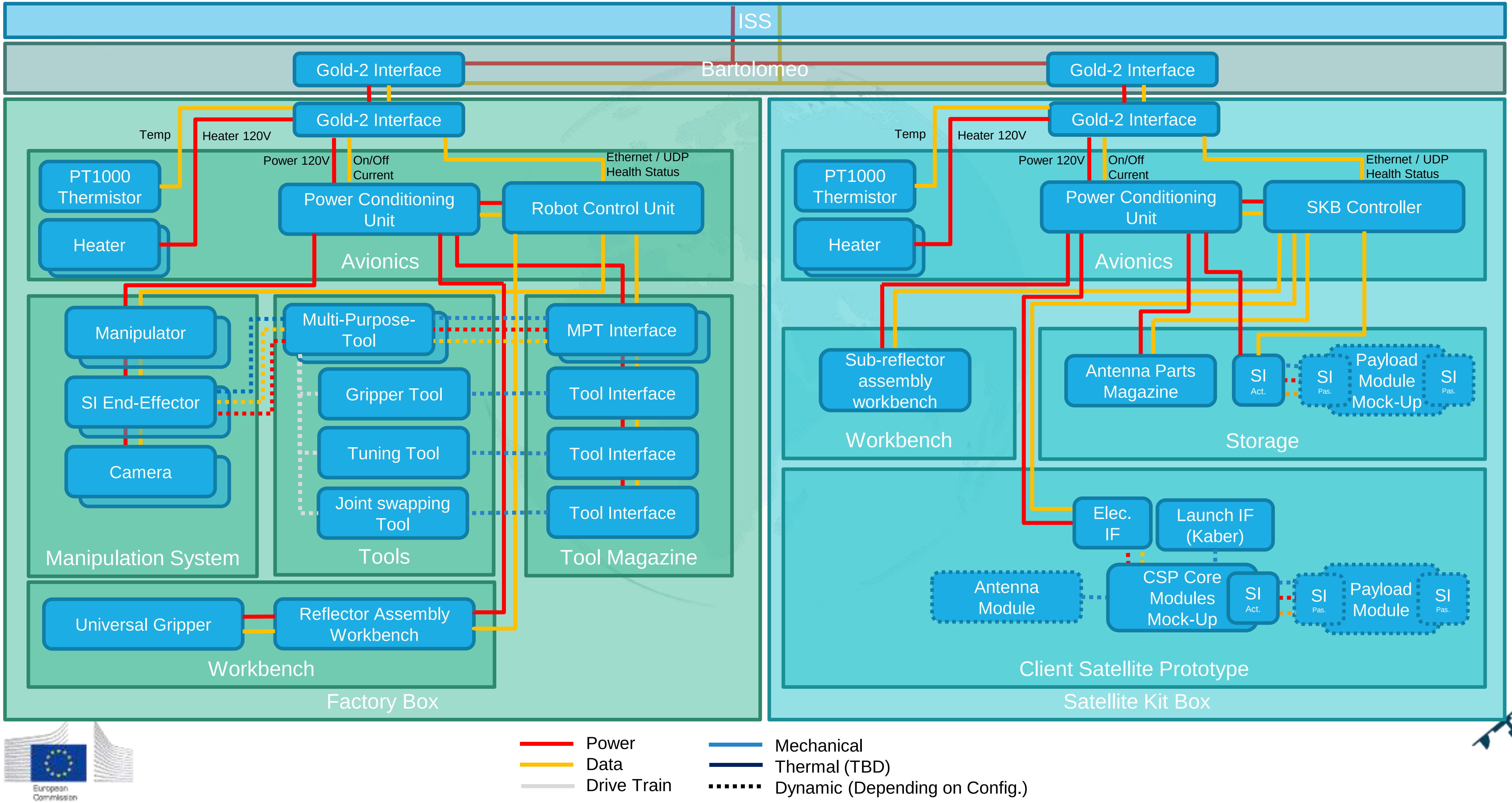


Interface and refuelling

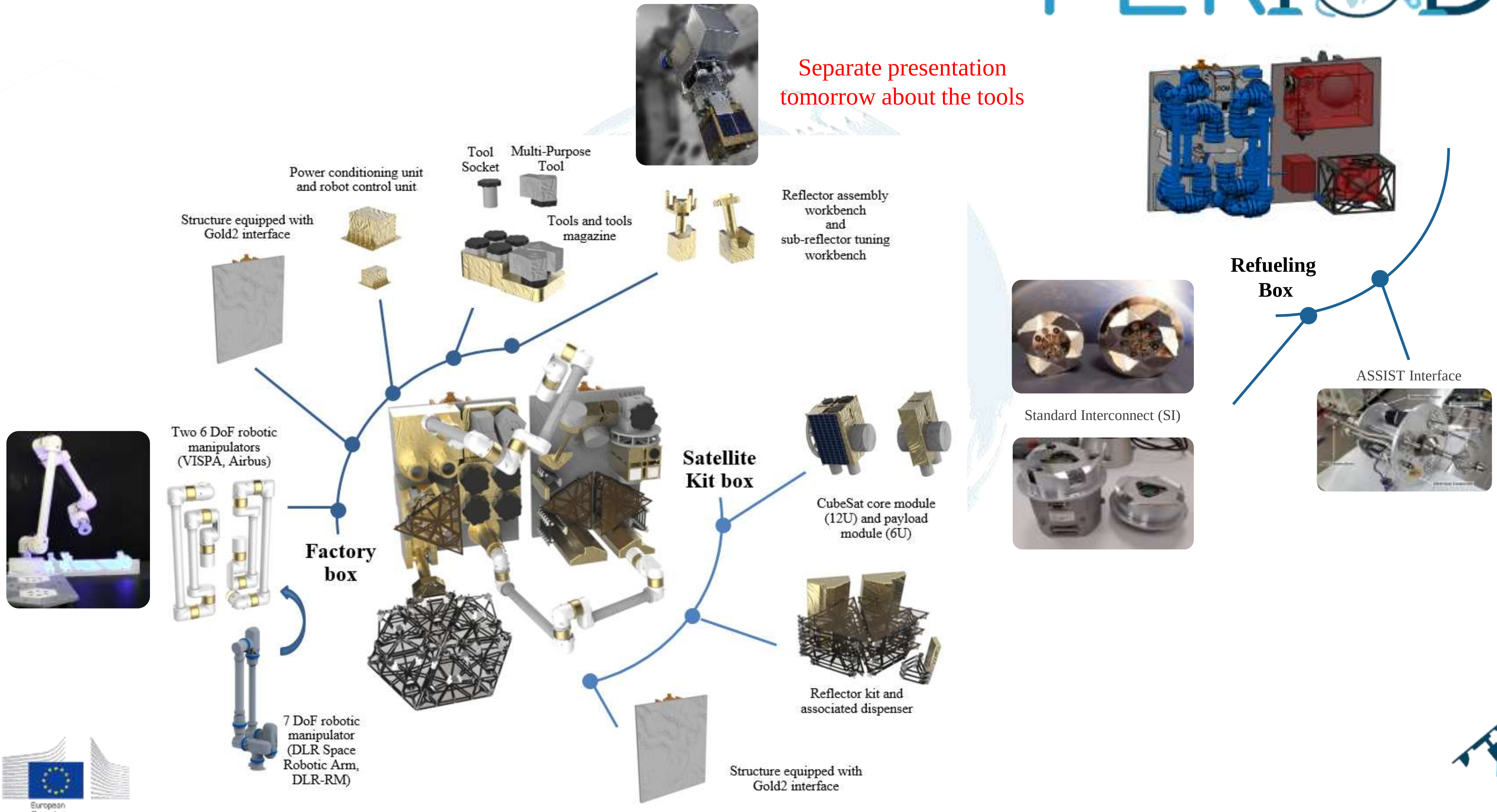


System Definition

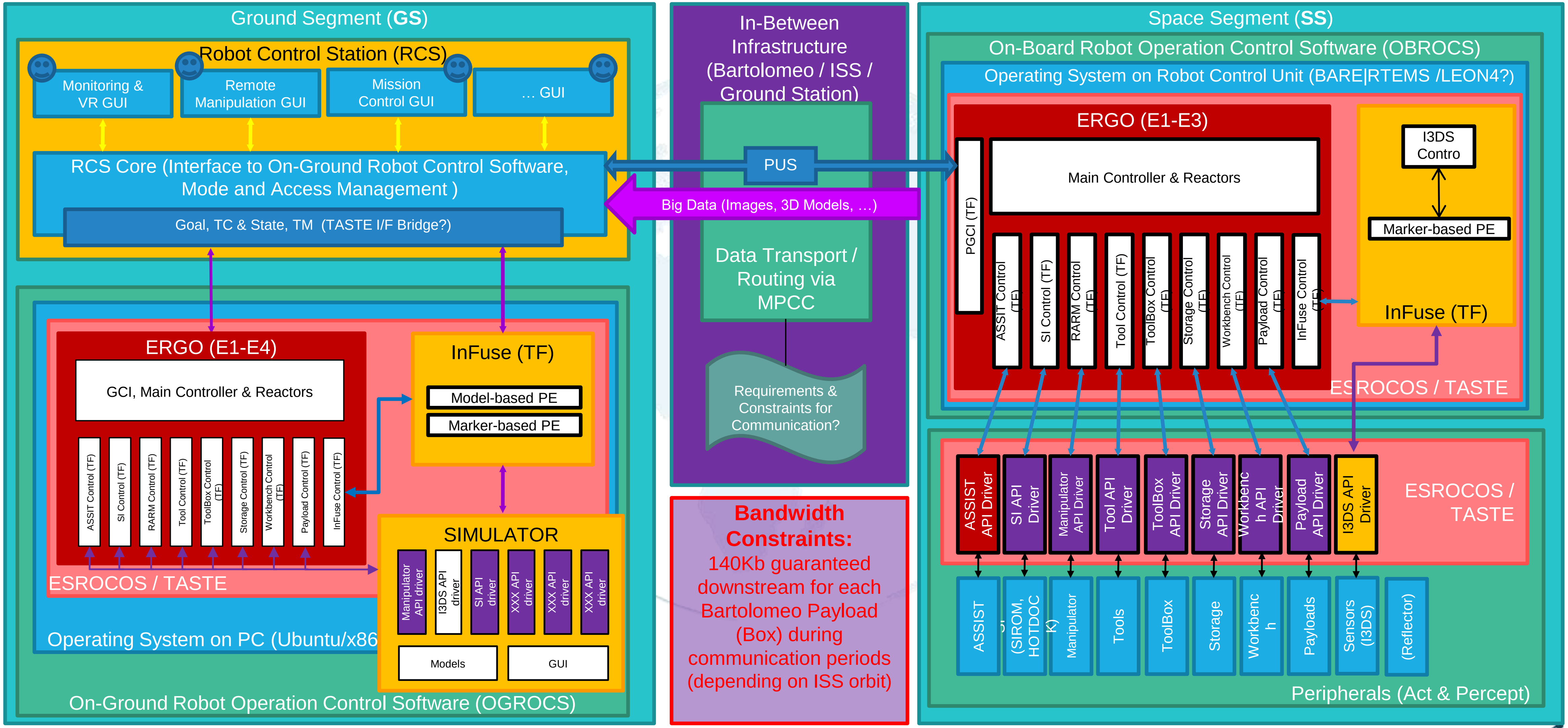
ISMA Factory Hardware Architecture



ISMA Factory Hardware Building Blocks



ISMA Factory Software Architecture (Flight System)



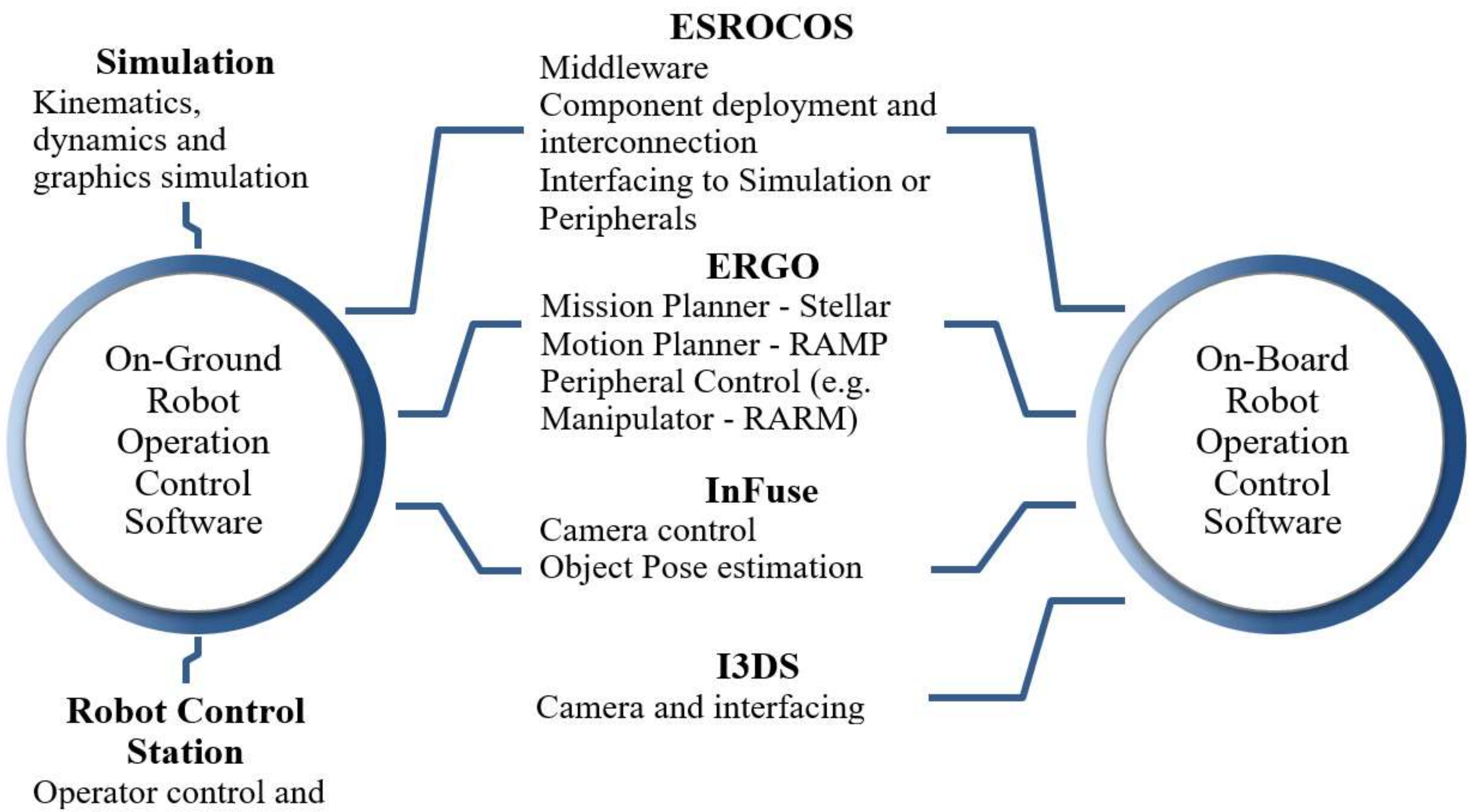
TASTE (PolyORB-HI)
HTTP
TBD (TCP/IP, other)

GMV
GMV-SKY
SpaceApps

DFKI
ADS

European Commission

ISMA Factory Software Building Blocks



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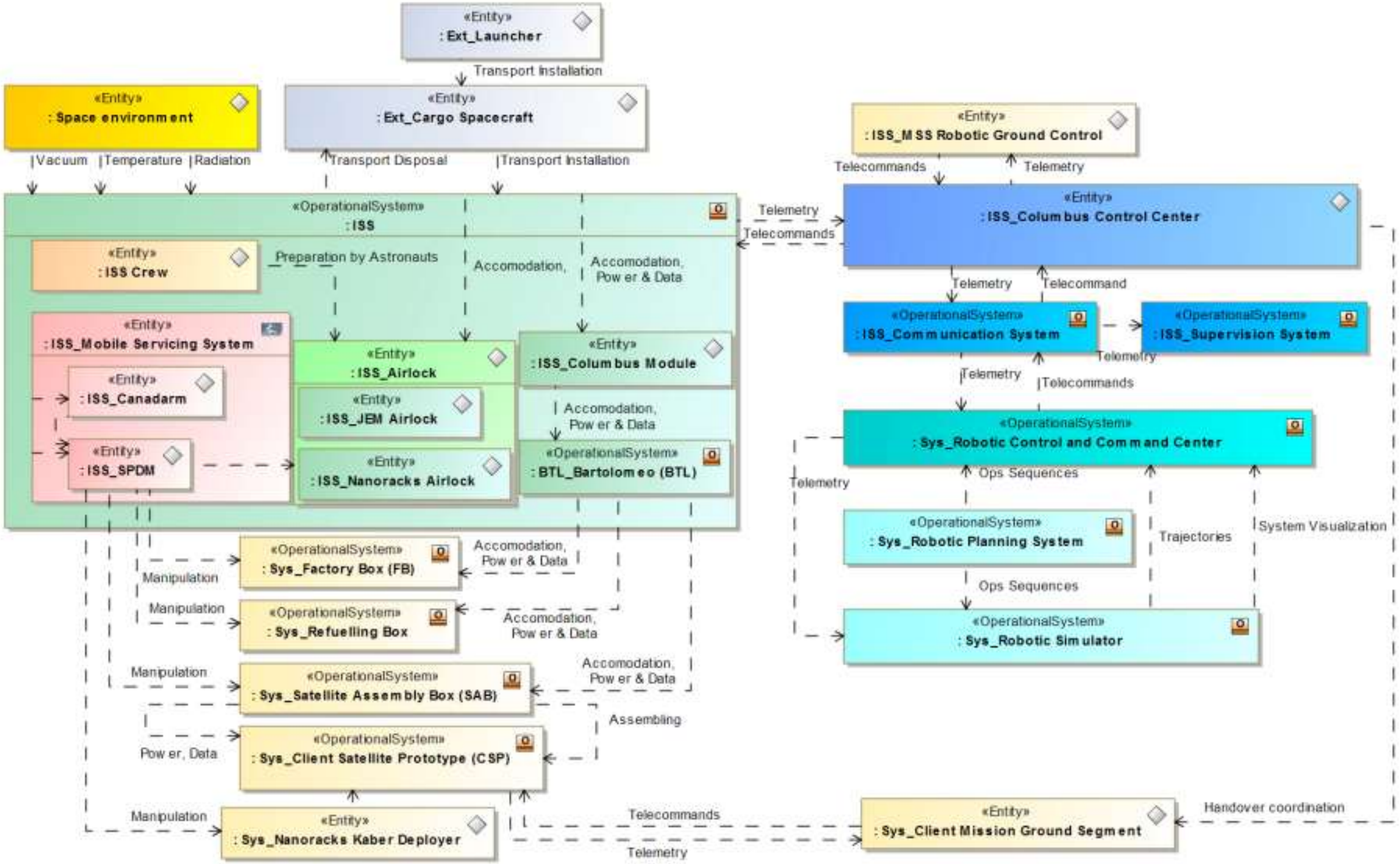
Operational Architecture Concept



European Commission

Thank you!

Acknowledgment

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Consortium

PERIOD

AIRBUS

gmv INNOVATING SOLUTIONS

SENER Aeroespacial

spaceapplications SERVICES

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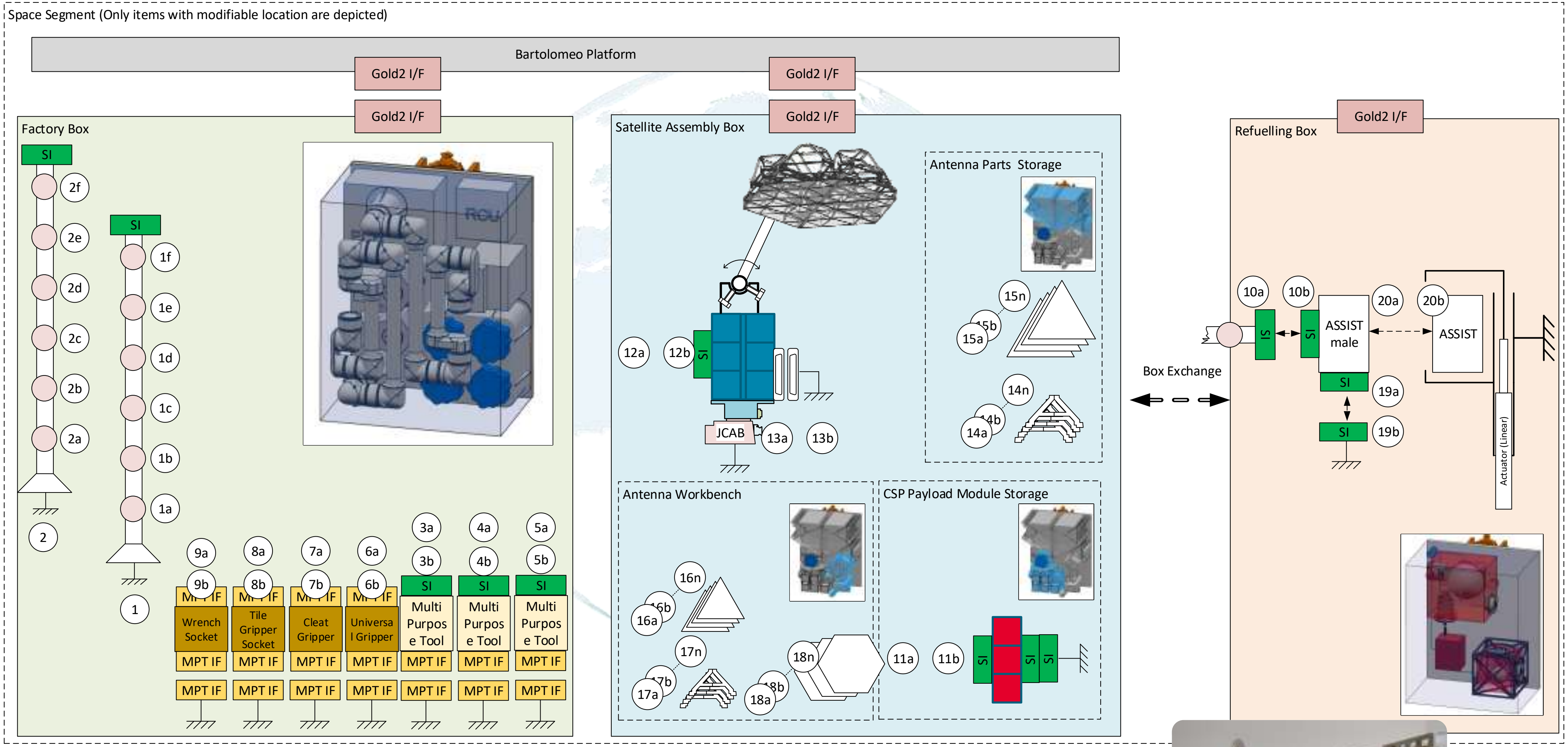
ISISPACE

easn Technology Innovation Services

Operation Gates



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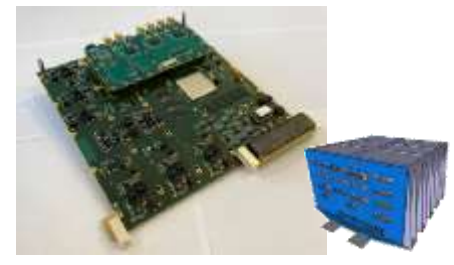
PM2 | 19.05.2022 | Online

Candidates

SPINAS	ZUP (DAHLIA EM)	Q8S	e.Cube
			
SPARC - LEON4	Xilinx Zynq UltraScale+	Xilinx Zynq UltraScale+ & Microsemi ProASIC3	Intel Atom E3800 (Ruggedized modular PC104)
Airbus DS (Bremen, Germany)	Airbus DS (Elancourt, France)	Xiphos Systems Corporation (Canada)	Airbus DS (Bremen, Germany) based on Board from RTD Embedded Technologies, Inc. (USA)
TRL 6 Qualification in 2019, never used in space	Will fly first time end of 2022	Flying since September 2020	Operational on ISS since 2014 for different projects (e.g. Bartolomeo since 2019) Same processor used on Perseverance Rover on Mars

Procurement & Provisioning

Three RTD boards ordered as SDM (one with CAN Interface board)

- Delivery date 17.06.22

CML24BT: Intel® Atom E3845 Ultra Low-Power SBC

Two additional Intel Atom industry PCs ordered as breadboard

- Start development on target asap (e.g. Cross-Compiler)
- Delayed delivery due to availability

Joy-it Joy-IT HEAVY02
Intel-E3845 4GB 1TB HD Industrie PC Intel® Atom® E3845 (4 x 1.91 GHz / max. 1.91 GHz) 4 GB 1 TB

Simulation Status

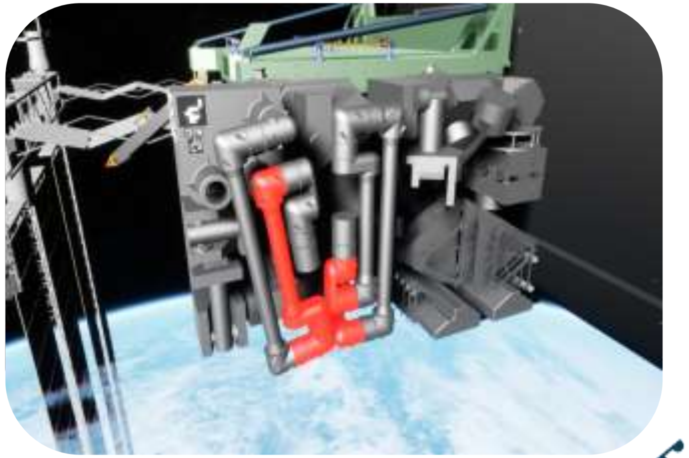
Development of 2 use cases
- Virtual Testbed
- Status Visualization

3 CAD model versions of Boxes
- Rig the manipulators
- Dynamic properties
- Collision models
- Open loop control (direct kinematics)
- Environment updated with custom textures and dynamic illumination

Compatibility with Desktop and VR applications

3 workspace analysis

Communications
- Robotic Control Station
  - Historic Data: Retrieve information from RCS to display robot status (Status Visualization through HTTP)
  - Telemetry: Send and receive real-time data as testbed (Virtual testbed through SocketIO).
- InFuse: Database for computer vision algorithms with chessboard and ARUCO markers.
- ESROCOS: Real-time TCP-IP streaming for robot control, updated to new data-types.



Breadboard Simulation
- compatible with all previous features and with KUKA IWA 14.

European Space Robot Control & Operating System

(OG1 ESROCOS, GMV-SKY)

ESROCOS

taste

A tool-chain targeting heterogeneous embedded systems, using a model-based development approach

ESROCOS pre-development status

Status

- ESROCOS, ERGO, InFuse and I3DS Integration
  - Infuse's marker pose estimator and ERGO's agent integrated as ESROCOS components
- Manipulator peripheral driver development
  - Interfaces with real robot through UDP and the simulator with TCP
  - Tested on simulator and with real robot
  - Provided support for integration with RARM

Next steps

- Provide support for SI driver integration & implement SI driver for simulator
- Add elected breadboard as a target in TASTE
- Continue testing, validating and refining ESROCOS & TASTE SW and interfaces on RISMAT, an industrial relevant environment, for reaching TRL5.

European Commission

European Robotic Goal-Oriented autonomous system

(OG2 ERGO , GMV)

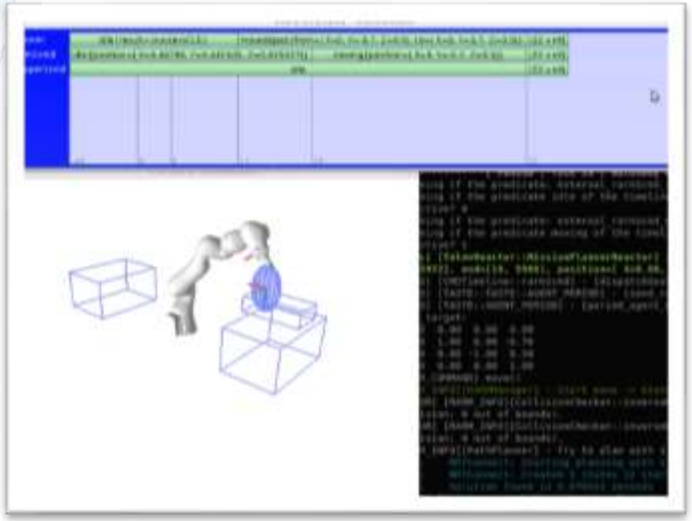
ERGO pre-development status

Status

- ERGO AF tailored and customised for PERIOD and RISMAT testbed (On-Ground/Board Models) and integrated with ESROCOS
- Agent & timelines customised for RISMAT tested current status (INFUSE & KUKA)
- Integrated and tested interactions (CMD&TM) with INFUSE (TASTE interfaces)
- ERGO RAMP tested with LOCARM & KUKA (iiwa R14) manipulators models (URDF)
- ERGO RARM Control TF (Functional Layer) integrated and tested with KUKA manipulator API through C/C++ & UDP/TCP interface (based on ESROCOS)
- ERGO RAMP kinematics integrated and tested with KUKA & Simulator, excluding RISMAT scene 3D models
- Currently integrating ERGO with RCS (Robot Control Station) API.

Next steps

- Inclusion and testing of RISMAT scene 3D models
- Integrate and test the generic SI (Standard Interconnect) API
- Assessment and testing of ERGO SW on RCU breadboard (eCube)
- Continue testing, validating and refining ERGO SW and interfaces on RISMAT, an industrial relevant environment, for reaching TRL5.



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Infusing data Fusion for space robotics (OG3 InFuse, SpaceApps)

INFUSE pre-development status

Status

- Handover PERIOD specific tasks & algorithms performed from Irene to Andres
- Breadboard simulation is ready to generate synthetic images
- ARUCO and Chessboard marker detection tested
- InFuse integrated with I3DS and ERGO

Next steps

- Camera optics validity confirmation
- Camera position fine tuning & markers size & position definition
- Marker-based estimator tests (w/ simulated datasets)
- Continue testing, validating and refining INFUSE SW and interfaces on RISMAT, an industrial relevant environment, for reaching TRL5.

Integrated 3D Sensors' suite (OG4 I3DS, SpaceApps)

I3DS pre-development status

Status

- Handover PERIOD specific tasks & algorithms performed from Irene to Andres (temporarily – recruitment of new staff in progress)
- Camera received from ADS
- I3DS integrated with INFUSE

Next steps

- Camera testing and integration in I3DS [ongoing]
- Continue testing, validating and refining I3DS SW and interfaces on RISMAT, an industrial relevant environment, for reaching TRL5.

12. Breadboard integration status

Breadboard Integration – Revisiting Objectives

- Continuous integration, testing, evaluation, optimization and demonstration of the developed technologies in relevant operational scenarios and use-cases
- Targeting at following testing objectives with respect to hard- and software as well as robotic receiving and providing service systems:
    - Functional testing
        - Commissioning of individual components
        - Testing the correct interaction of integrated components
        - Testing the correct function and determining the characteristics and performances of individual and integrated components
    - Operational testing
        - Performing operations with Integrated providing service system including assembly, integration, and maintenance (exchange of modules) of receiving service system
        - Validation of the correct execution of work steps of the providing service system and test of integrated receiving service system

Breadboard Integration – Test-Use-Cases

Detailed Analysis of Use-Cases and Requirements – Necessary Modifications

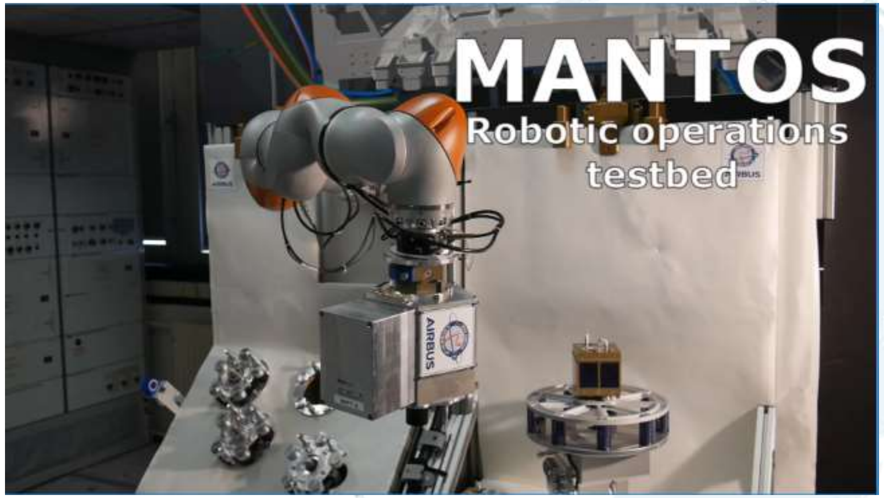
- Manipulator tool exchange use-case will not be demonstrated.
- All payloads shall be connected via standard interconnects (SI).
- Modifications of environment, obstacles and P/L positions due to limited work-space of the KUKA iiwa robot.
- Satellite mock-up and factory will differ in shape and size from system concept.
- Intel Atom-based OBC has been selected and shall be used also for the breadboard demonstration.
- Representativeness of illumination conditions will be limited. This is left to Phase B2/C demonstrator.
- No gravity off-loading is currently foreseen and also not needed for the KUKA.
- Usage of LOCARM/VISPA is currently not foreseen.

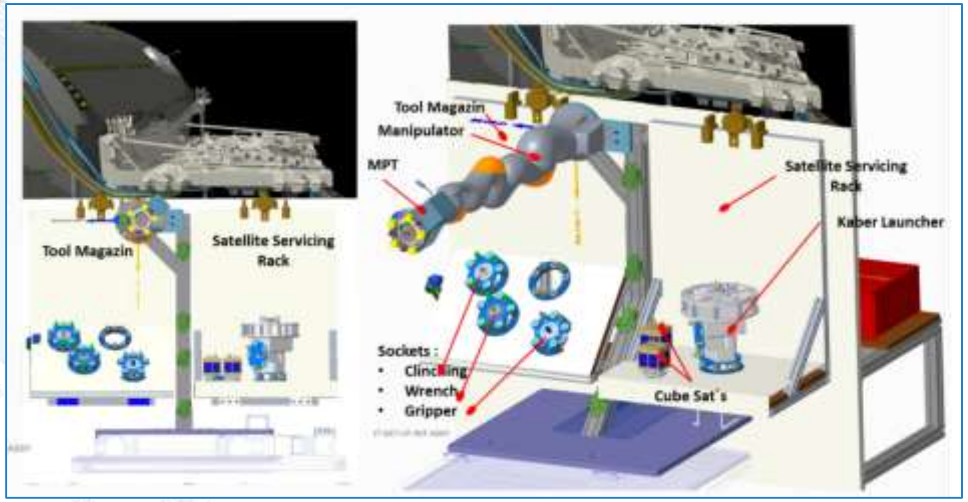
Main Objectives of the Breadboard Demonstration

- Full integration of relevant S/W building blocks into TASTE/ESROCOS framework including ERGO and control of H/W elements, mainly: Standard Interconnects (SI), camera, KUKA robot.
- Demonstration of robot control incl. trajectory planning, P/L exchanged based on SIs, marker-based pose-estimation.

Breadboard Integration – Update of Testbed

- Existing RISMAT testbed at Airbus shall be re-used and modified for planned test-activities:

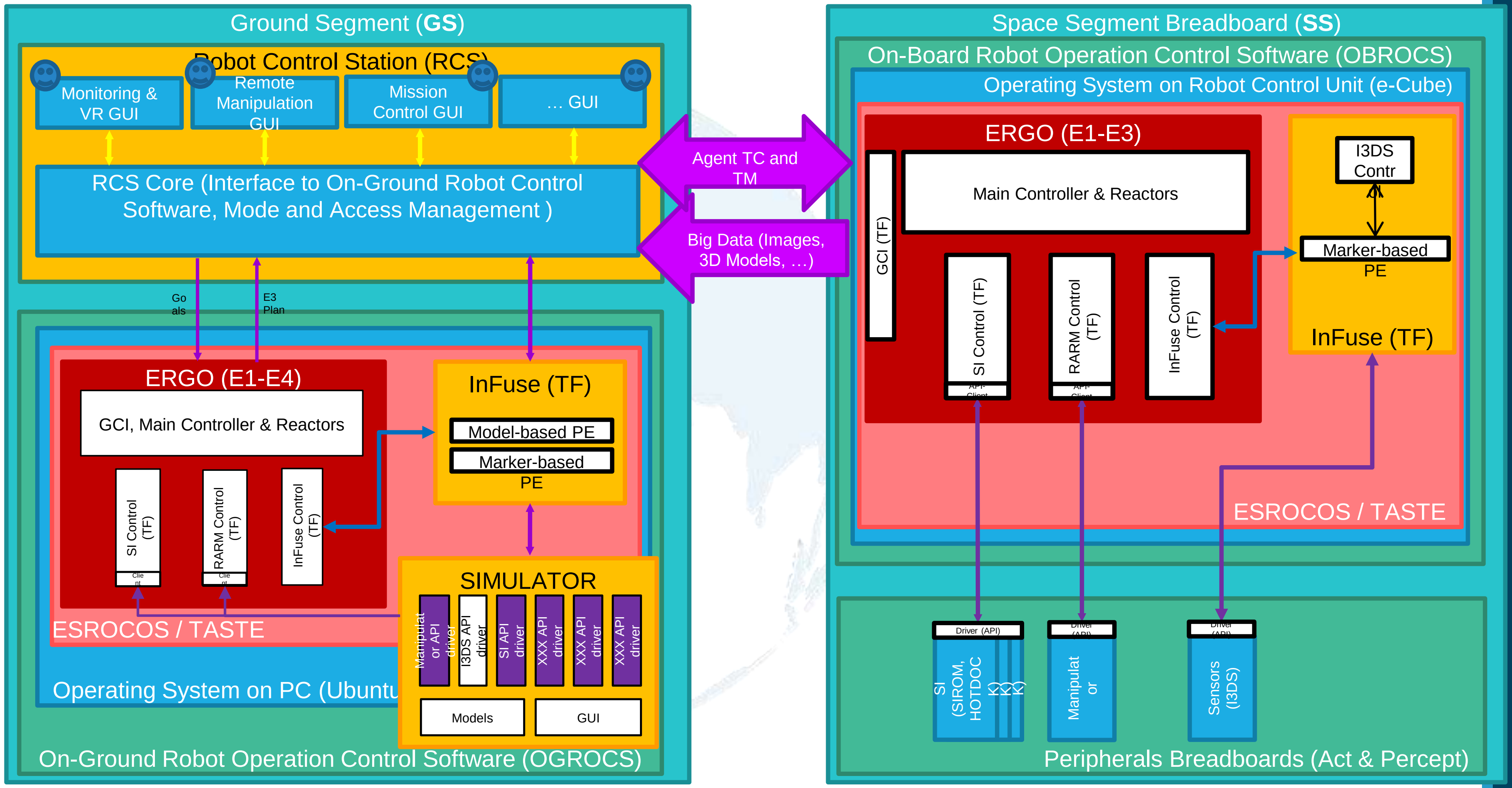




- It mainly provides
    - A KUKA iiwa R14 industrial robot for manipulation purposes
    - Two workspaces of Bartolomeo box-sizes giving room for experiments, and payloads.

Breadboard Integration – Updated S/W Architecture

Reduced to core elements of Ph B1 BB demonstrator



TASTE (PolyORB-HI)
HTTP
UDP, TCP, CAN

GMV
GMV-SKY
SpaceApps
DFKI
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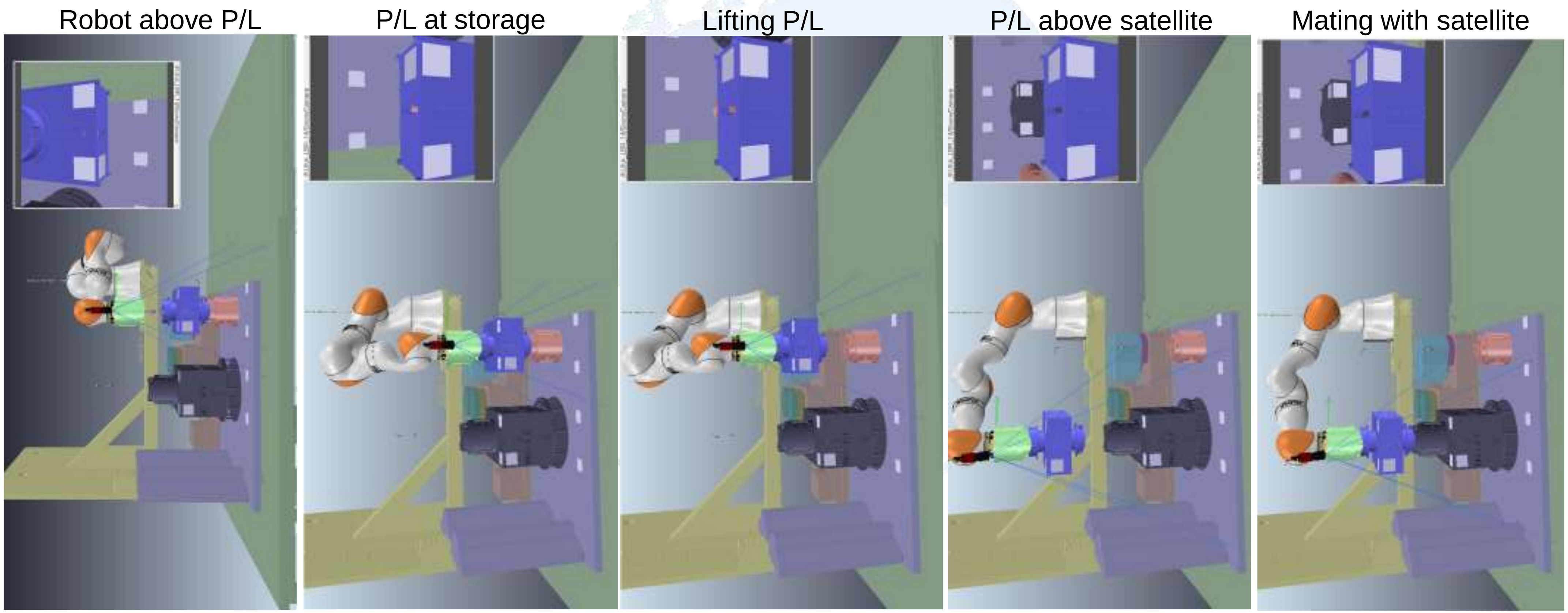
Breadboard Integration – Testbed Simulations

Some views of preparatory simulations (before passing the model to SpaceApps):

- Critical positions have been tested: Reachability and visibility of markers in camera FOV

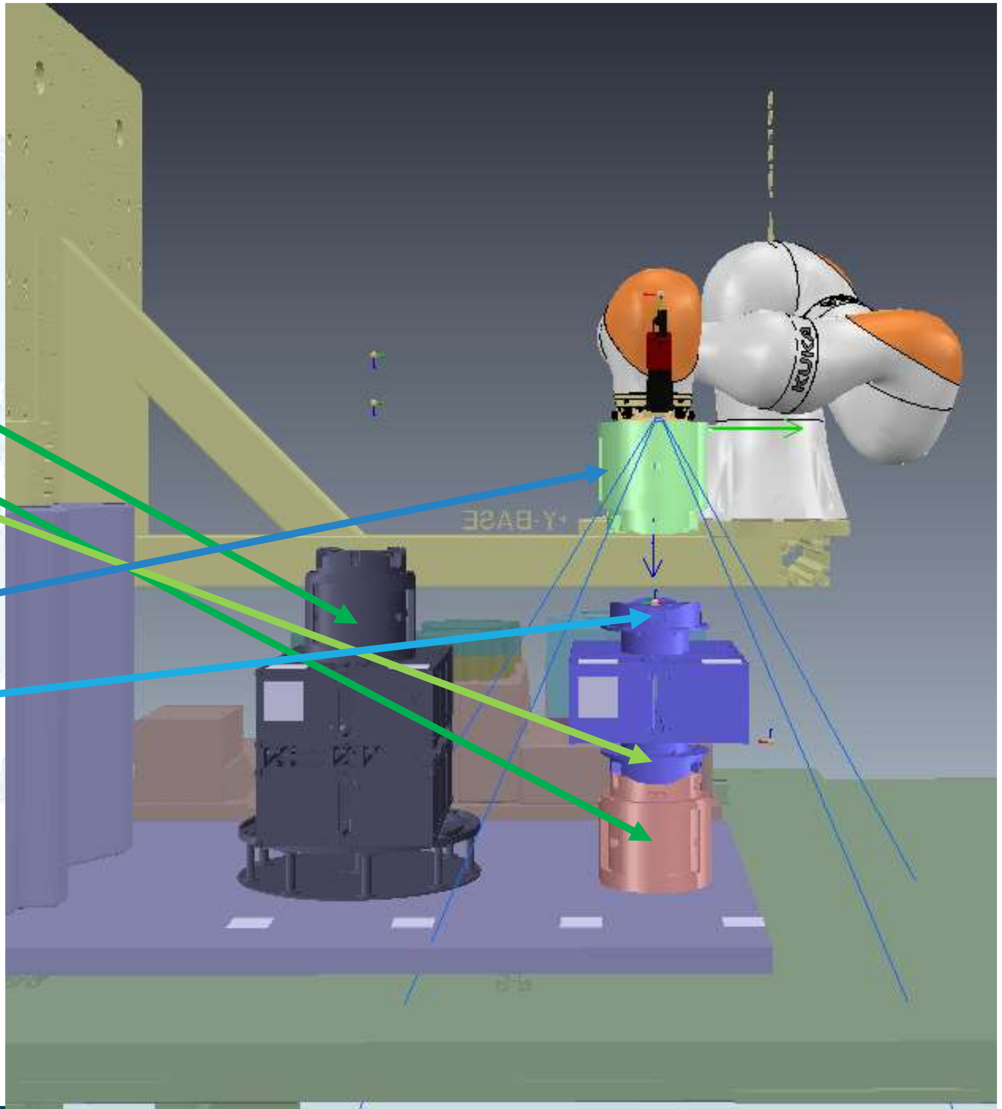


Breadboard Integration – Testbed Simulations

Usage of both SIs in Breadboard:

- SIROM Interface
  - 1x Active: Satellite
  - 1x Active: P/L Storage
  - 1x Passive: P/L Mockup

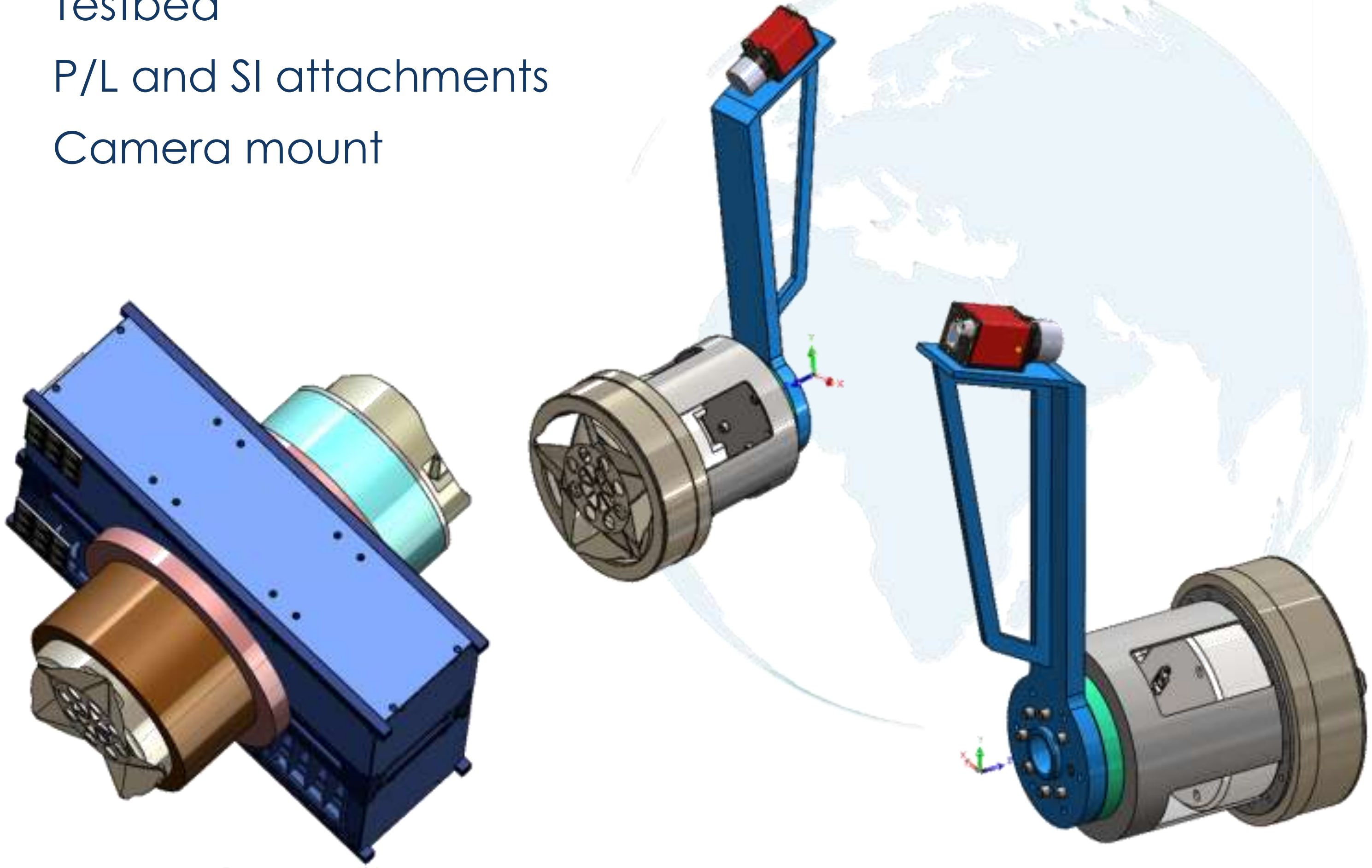
- HOTDOCK Interface
  - 1x Active: End-Effector
  - 1x Passive: P/L Mockup

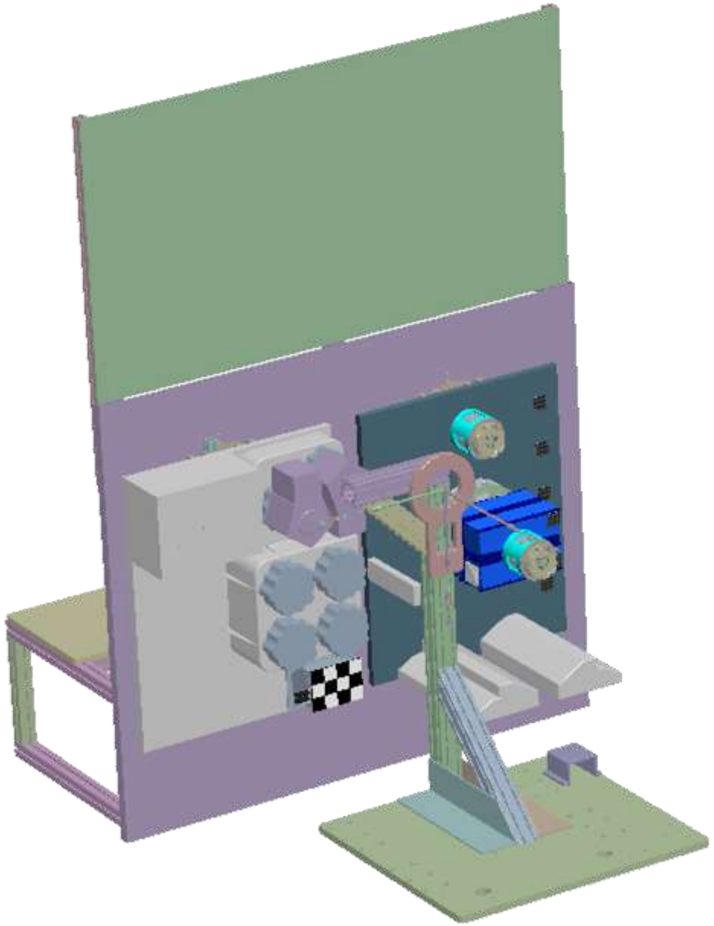


Breadboard Integration – Testbed Design

Updated design of RISMAT Testbed:

- Testbed
- P/L and SI attachments
- Camera mount





Breadboard Integration – Testbed Validation

Updated design of RISMAT Testbed:

- The current design of the updated RISMAT testbed has been passed to SpaceApps
  - For integration in the simulator
  - Testing of reachability, visibility and usability for trajectory planner…

After receiving the go, RISMAT will be procured…

Breadboard Integration – Implementation Status

PERIOD

Breadboard Update:

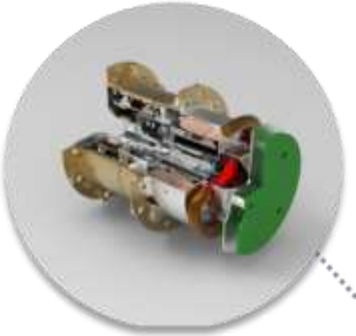
- Updated breadboard design is under check at SpaceApps
    - Critical points: Camera mount and visibility and consequences for trajectory planner
    - Once this has been checked, BB will be finally designed and procured.

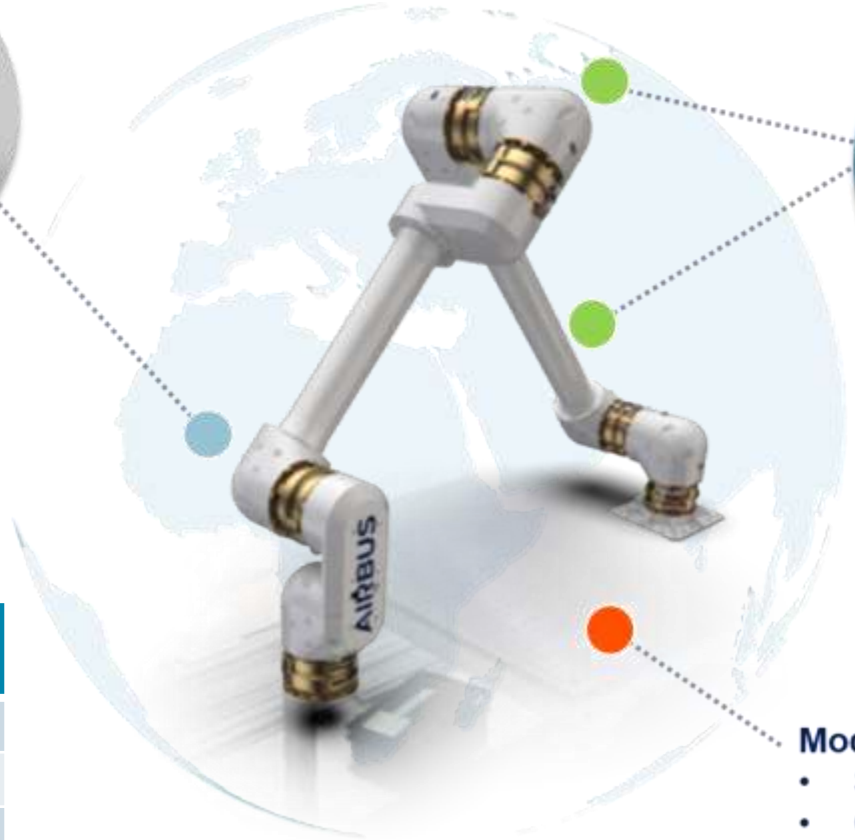
S/W Integration:

- I/F to KUKA robot from RISMAT facility has been provided to GMV
- GMV integrated it into ESROCOS as driver function. TM/TC of real KUKA robot from ESROCOS has been demonstrated (see video).
- Camera driver has been provided to SpaceApps for integration as i3DS driver.
- Standard Interconnects S/W API have been harmonized. Abstract I/F class has been defined and is currently used to implement ESROCOS functions for the SIs (SIROM/HOTDOCK and simulator).

13. LOCARM development status

LOCARM / VISPA





Self contained robotic joints

- Compact transmission
- In-joint motor control electronics
- High-resolution non-contact sensor
- 6 identical joints

Modular Mechanical structure

- Scalmalloy ALM
- Single piece tube/flange
- Ti and Al joint parts

Modular configuration

- Slender design
- Compact stowage
- With/without spherical wrist

Parameters	TRL4 Data *in 1g*
Mass	15kg
Number of DoF	6
Length	1767mm
Repeatability (1g)	0.171mm/ 0.049deg
Accuracy (1g)	<2mm/ 0.5deg

LOCARM / VISPA

Ongoing development

→ **Development of a TRL6 Manipulator.**
→ **Development of advanced arm control with TRL4 robotic arm.**
→ **Exploration of advanced modular concepts (i.e. joint swapping)**

Compliance Control

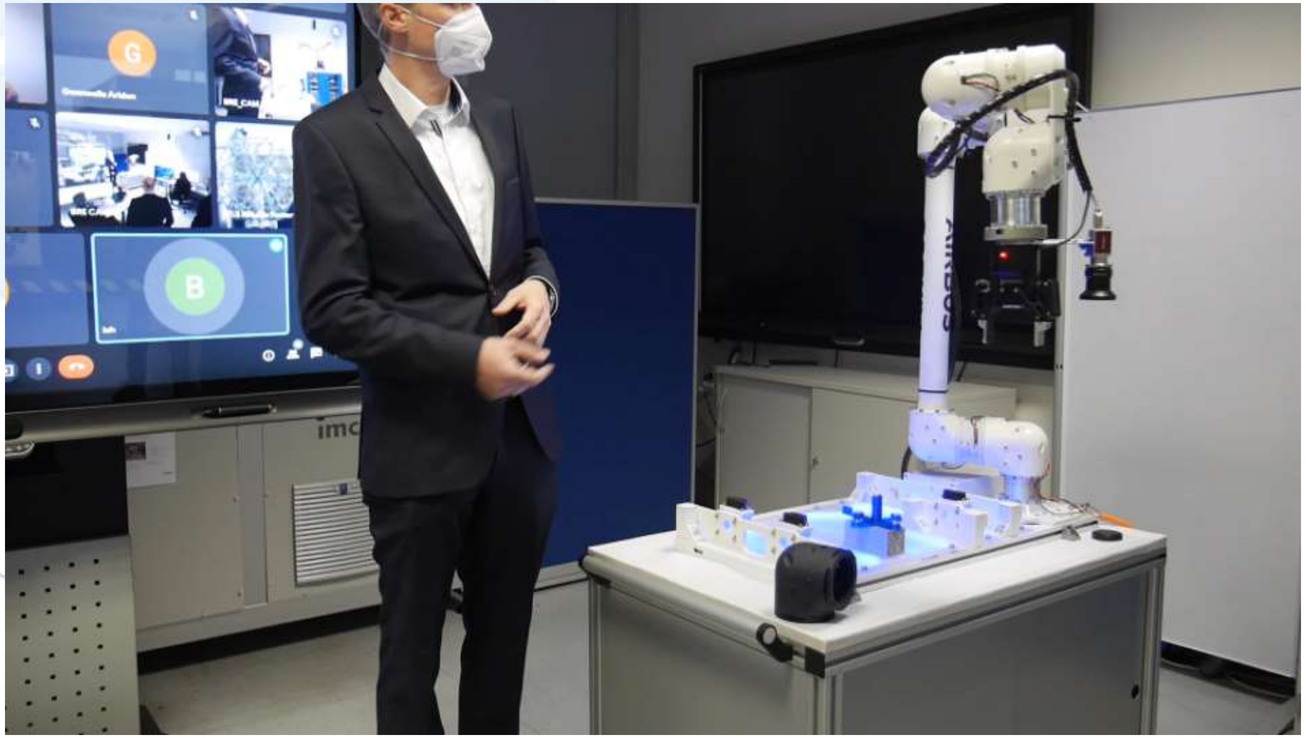
Compliance control for LOCARM utilizing torque estimation based on current measurement
dSPACE based **Hardware-in-the-loop (HIL)** real time testbed for robotic joint and arm
High fidelity simulation of the LOCARM
Model-Based development environment & auto-coding for robotic control SW
Test and performance analysis with LOCARM DM

Results so far:

- Model-based Development & Verification Environment set up
- Single Joint reference experiments for model correlation and controller calibration
- Arm control with compliance control on joint level

Ongoing activities:

- Compliance control in Cartesian space ongoing
- Performance Analysis ongoing



European Commission

DLR Co-Funded R&T Project VISCOL – Visual Servoing for Control of Low-Cost Arms

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

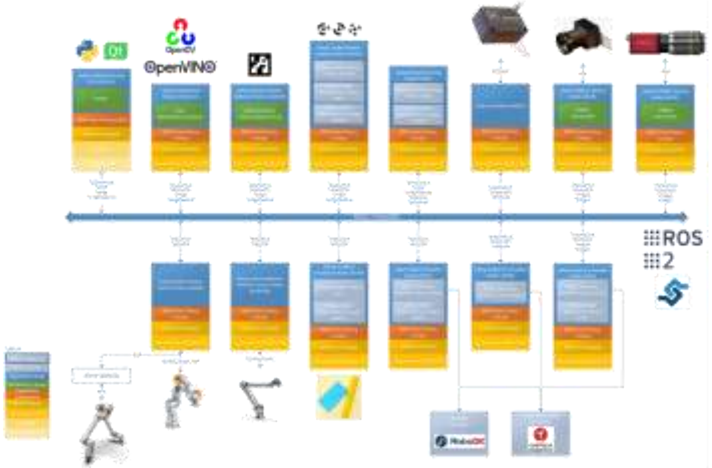
Background:
- Low-cost space-manipulators are less precise than industrial robots due to less powerful sensors, limited stiffness and thermal bending
- Traditional look-and-move strategies may not reach sufficient accuracy for ISMA processes (desired: <1mm)

Envisaged Strategy in VISCOL:
- Apply visual servoing control to visually guide the robot as close as possible to the target.

Objectives of VISCOL:
- Systematic investigation of visual servoing techniques for LOCARM control
- Development of VS framework
- Prototypic implementation with TRL 4-5
- Application to KUKA and LOCARM
- Dedicated measurement campaigns for estimating achievable accuracies

Target Application: ISMA scenario

Project Status:
- Started in 02/2022
- PM1 held in April
- Requ. analysis performed
- Setup of simulation environment and prototypic implementation of VS framework
- First results in simulation and for KUKA H/W demonstrated.
- Full implementation in ROS2 based on embedded VS library which is under development in VISCOL:
- Test-plan defined including elaborated ground-truth measurements



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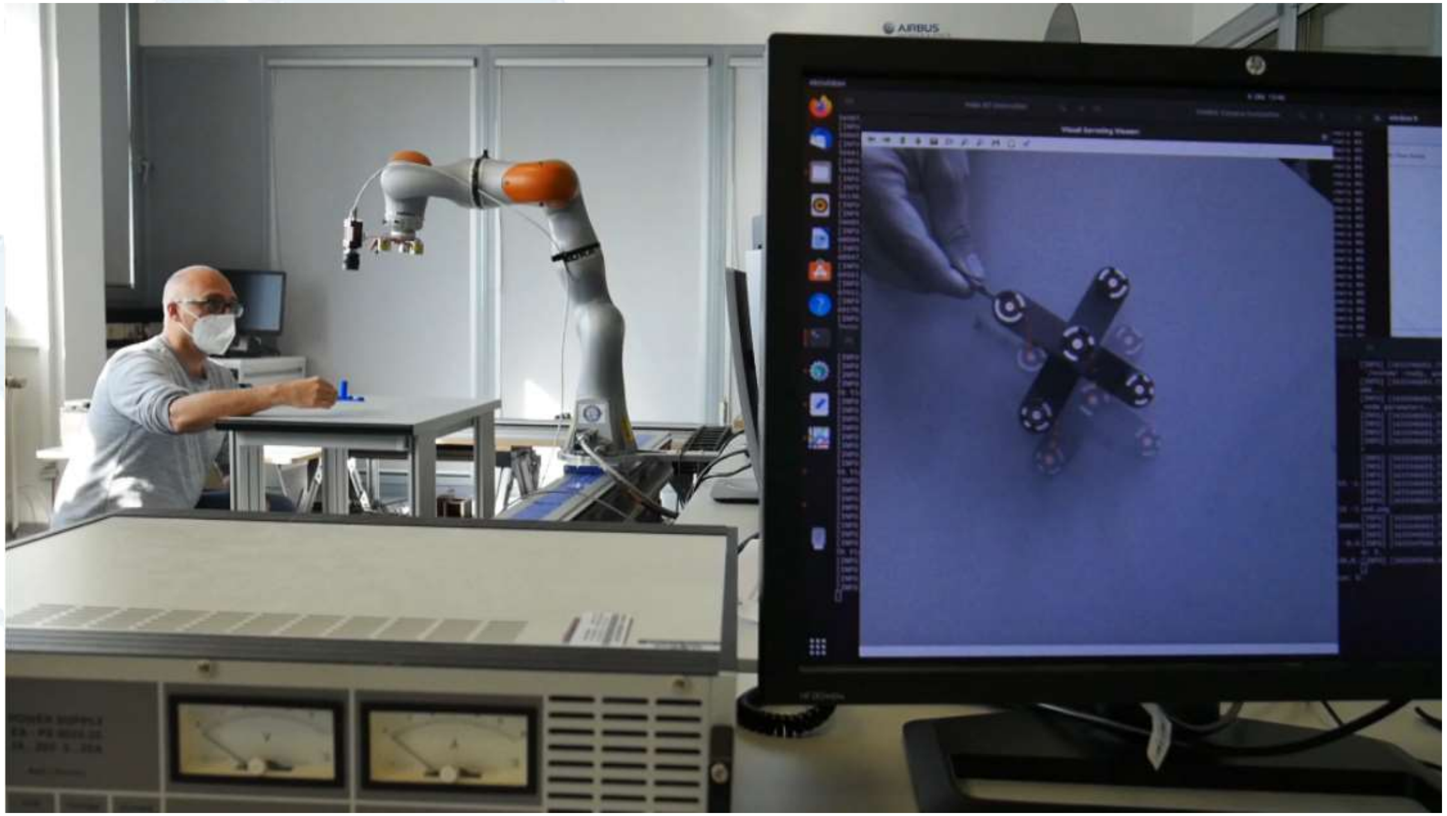
First results for real robot H/W: KUKA iiwa

- Preliminary implementation performed for KUKA iiwa and 1 single camera based on marker-tracking
- Next step shall be the integration to VISPA/LOCARM
- Beside full-blown VS techniques, also iterative look-and-move-strategies will be considered

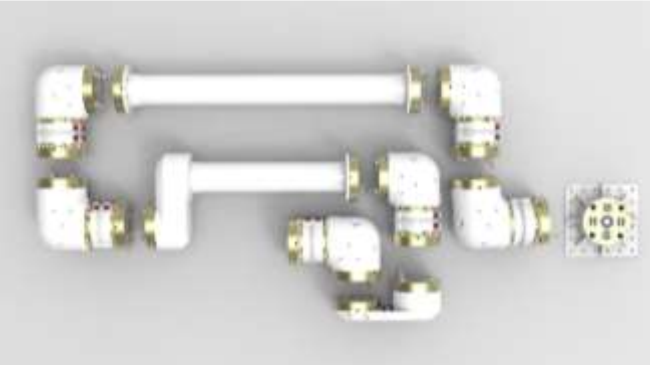


Schedule of VISCOL:
- Started in Feb 2022
- Ends in Jan. 2023
- PM2 in Oct. 2022
- 1st measurement campaign schedule for beginning of September
- Target is TRL 4-5

Joint Swapping

- → To address high duty cycle activities e.g. large in-space assembly – robustness and dependability is critical
- → Design focuses either on high level of in-joint redundancy **OR** architecture design to integrate ***joint as a consumable***
  - → Swappable joints

Modular joints



Modular design