WE LOOK AFTER THE EARTH BEAT

Exploring the Planets : avionic system challenges and opportunities

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  - COTS platforms
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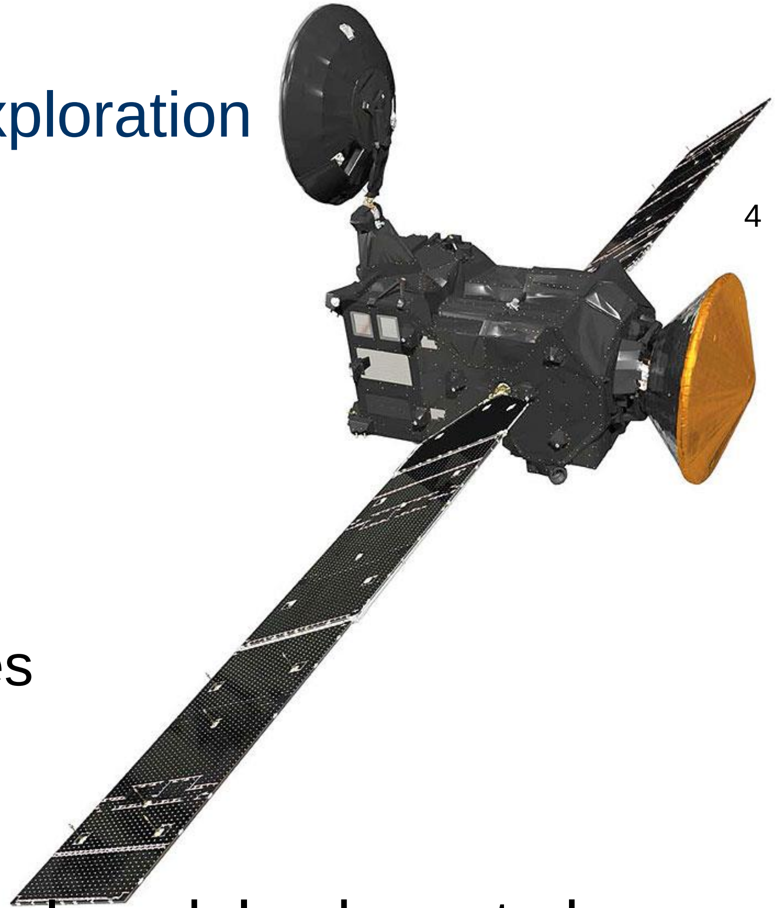
Complex space system configurations for exploration

Complex space system configurations for exploration



- Planet exploration means to perform:
  - cruise to reach the target planet
  - approach the planet orbiting and observing it
  - landing on the surface
  - explore the planet surface using rover vehicles
  - collect Soil sample using drill or robotic arms
  - send it back to Earth for scientific analysis
- Complex space systems composed by several modules have to be designed. Each module has a specific function.
- Avionics design must:
  - distribute functions among these modules according to the mission needs
  - consider key requirements of each mission

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Complex space system configurations for exploration: EXOMARS 2020

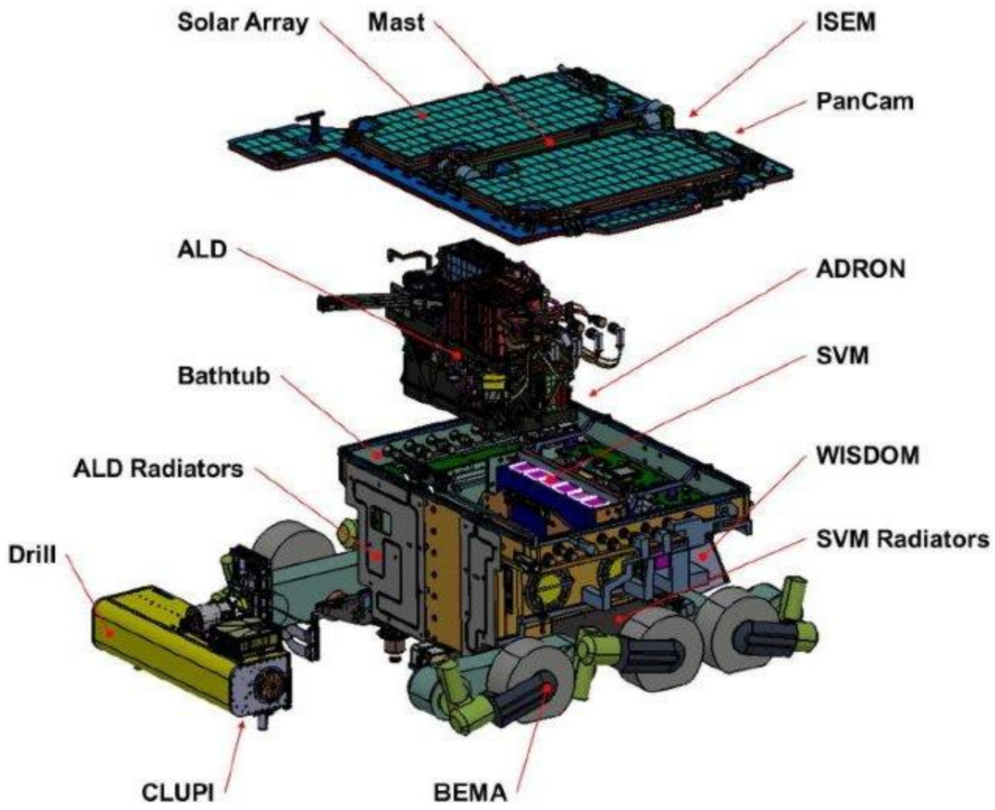
Objectives:

- search for signs of past and present life on Mars
- investigate the water/geochemical environment as a function of depth in the shallow subsurface
- characterise the surface environment

All scientific investigations are carried out in situ using:

- Rover System Pasteur Payloads
- Surface platform scientific instruments

Scientific results are sent to ground using the RF link based on Orbiters



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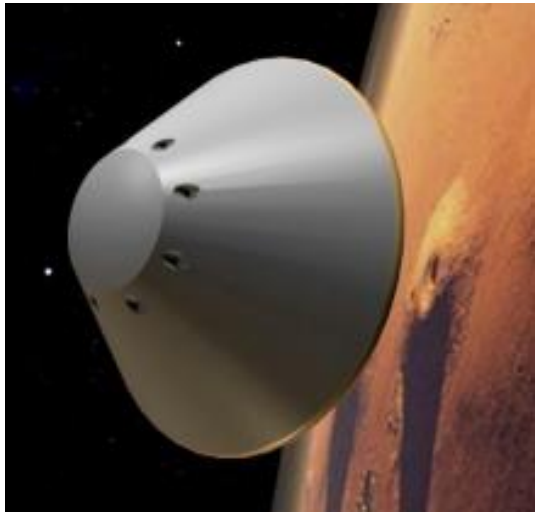
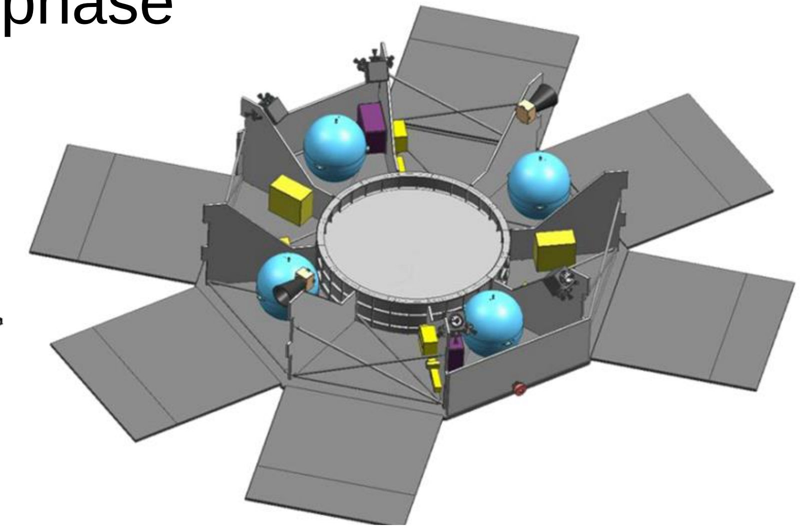
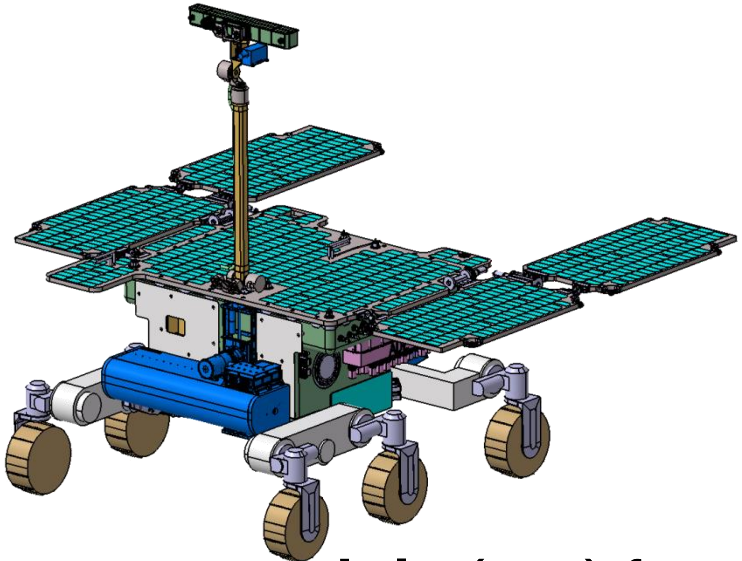
Complex space systems configuration for exploration: EXOMARS 2020

Descent Module (DM)
for EDL phases

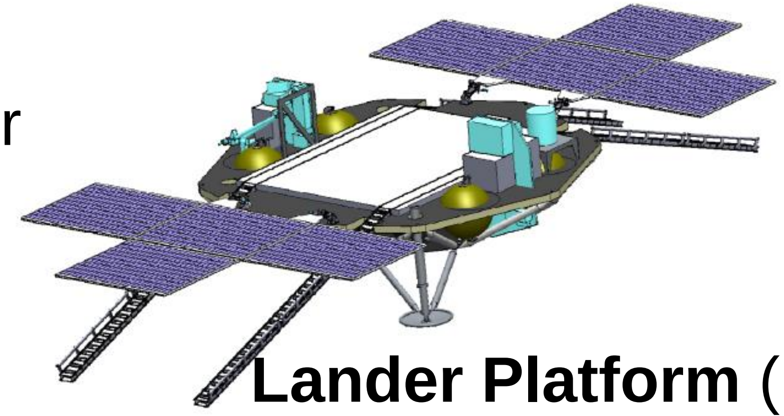


Carrier Module (CM)
for Cruise phase



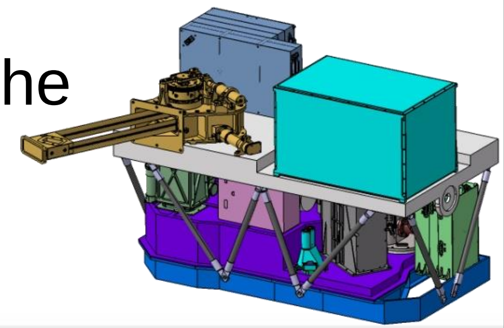


Rover Module (RM) for
Mars Surface Phase



Lander Platform (LP)
for Mars Surface
Phase

ALD (PPL)
included in the
RM



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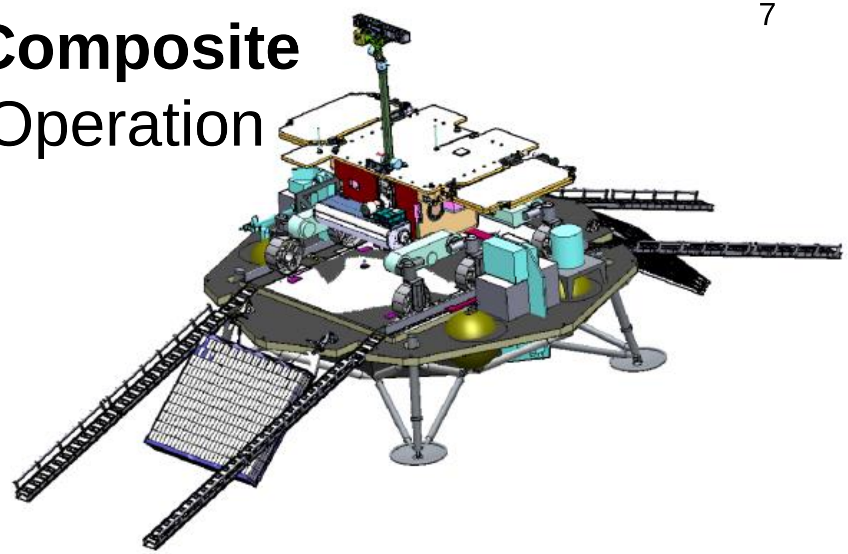
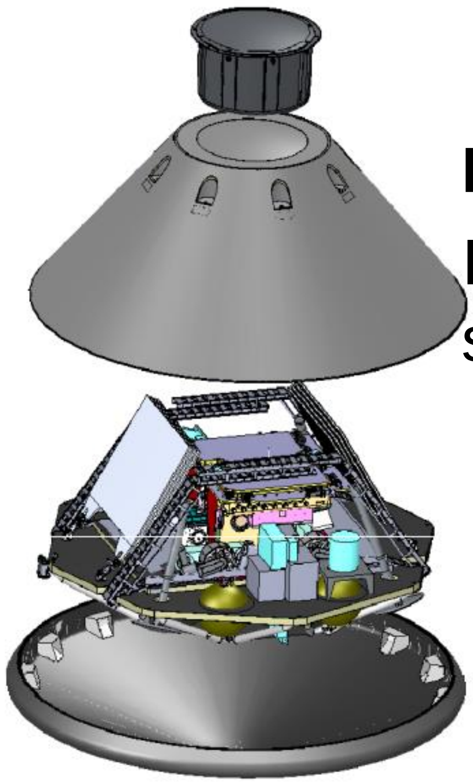
Complex space systems configuration for exploration: EXOMARS 2020



Lander Platform Composite

for the Early Mars Operation phase

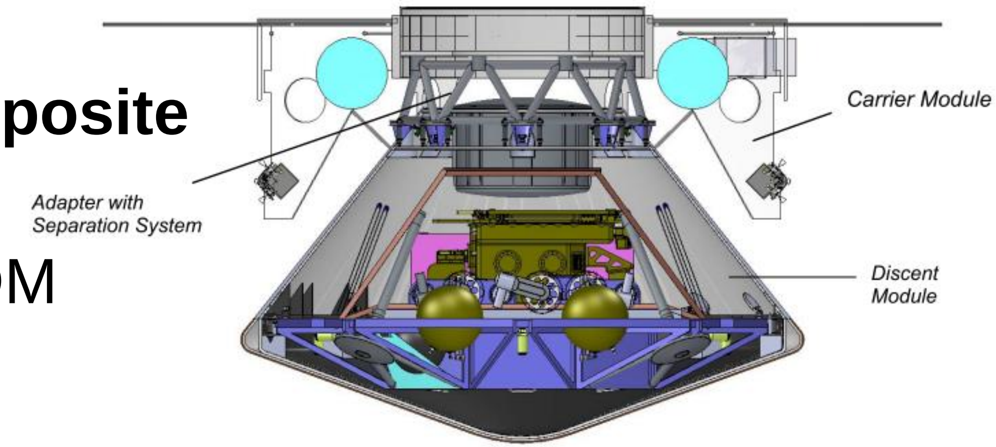


DM is also a Composite

Includes RM and LP in stowed configuration

Spacecraft Composite (SCC)

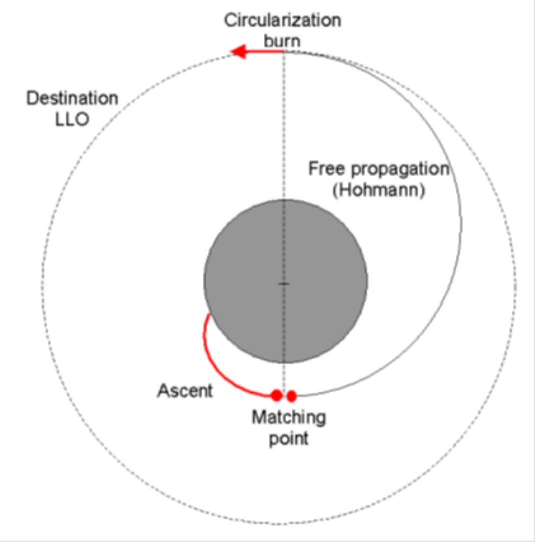
CM mated with DM

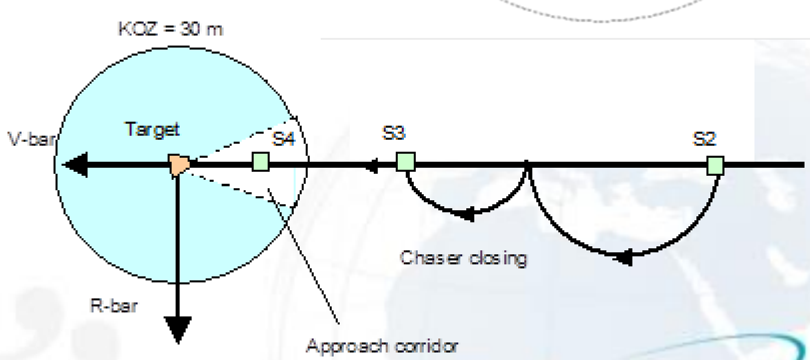


Complex space systems configuration for exploration: LPSR

Objective:

- Collect samples from Lunar South Pole and return them possibly with water ice content
- Scientific investigations are carried out in Earth Laboratories
- 2 Launches
  - Soyuz 2,1b for Orbiter Return Module
    - Orbiter vehicle
    - Earth Return Vehicle (Capture Mechanism)
    - Earth Return Capsule
  - Angara A3
    - Lander Platform
      - Sampling mechanism
    - Lunar Ascent Vehicle
      - Orbiter Sample Canister
- Ascent phase with RdV and OSC Capture





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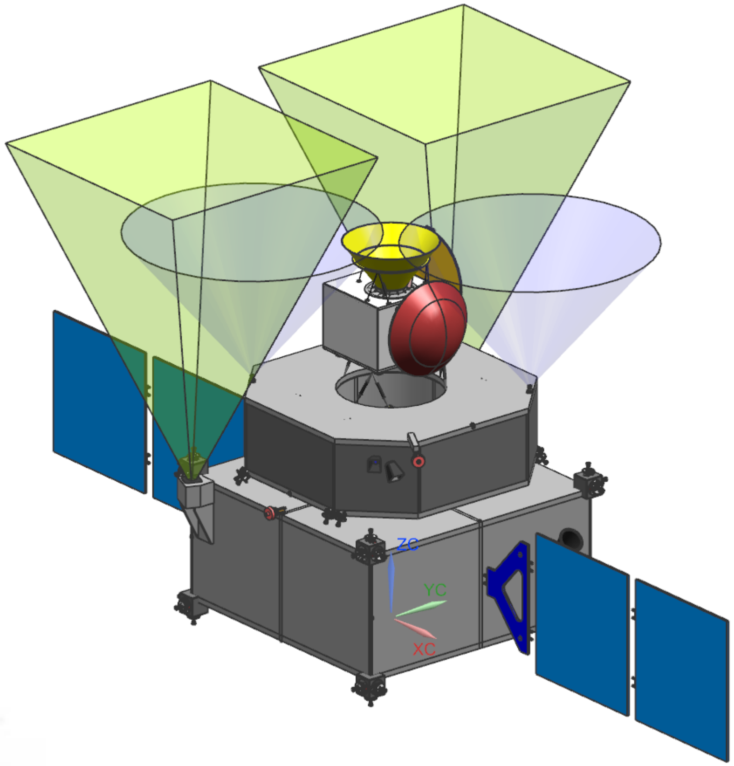
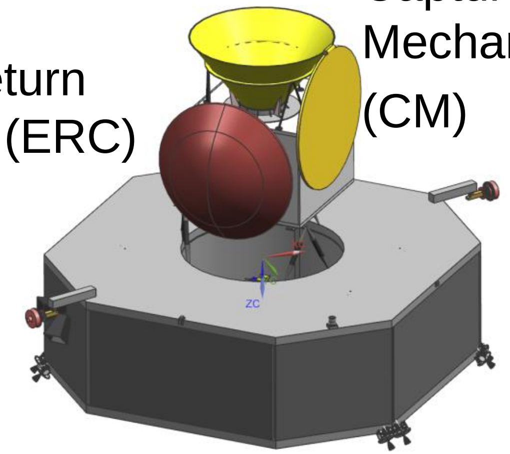
First Launch: Orbiter Return Module

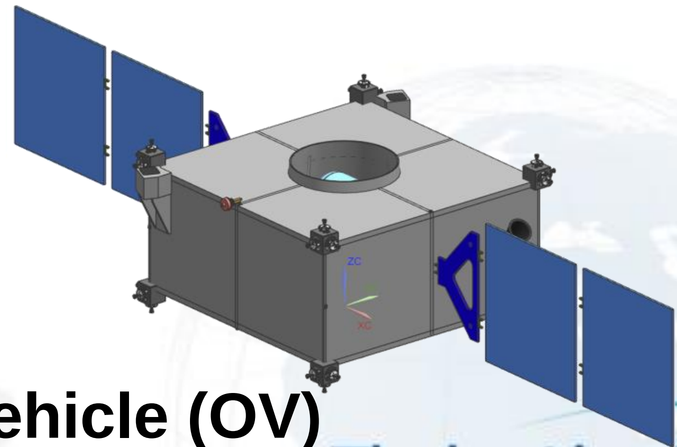


Earth Return Capsule (ERC)

Capture Mechanism (CM)



Earth Return Vehicle (ERV)



Orbiter Vehicle (OV)

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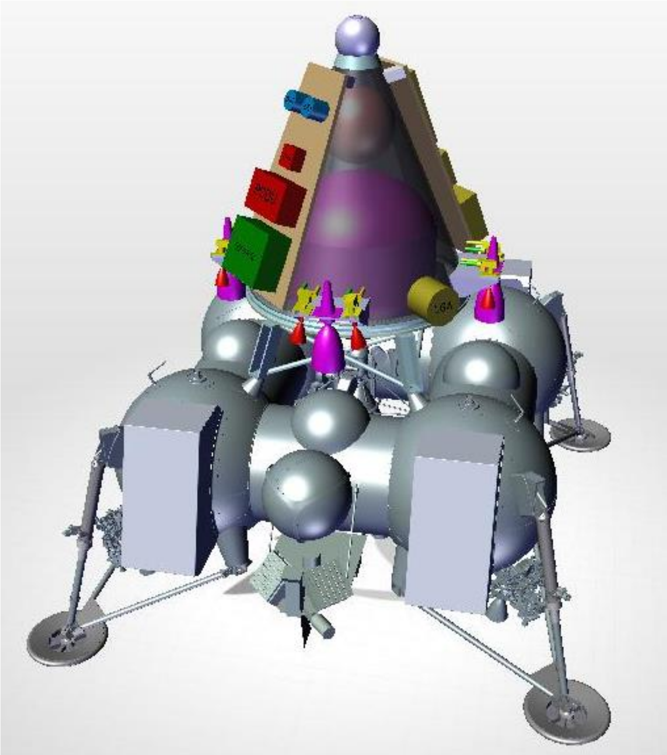
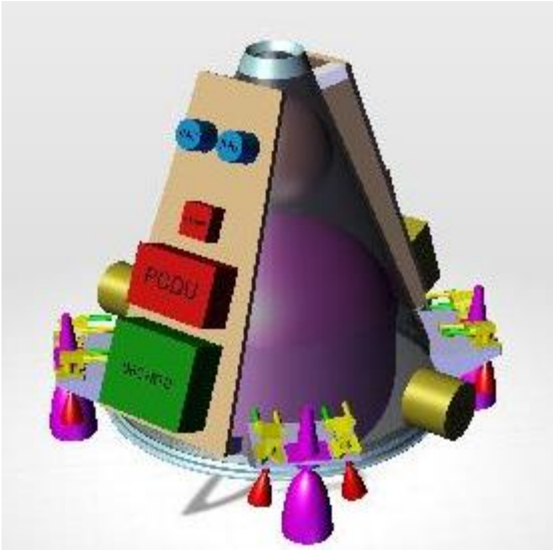
Second Launch : Landing Module

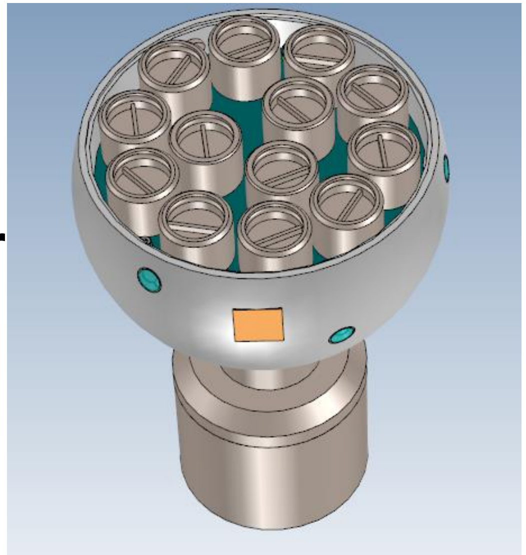
Landing Module (LM) composite :
Landing Platform (LP) + LAV + OSC

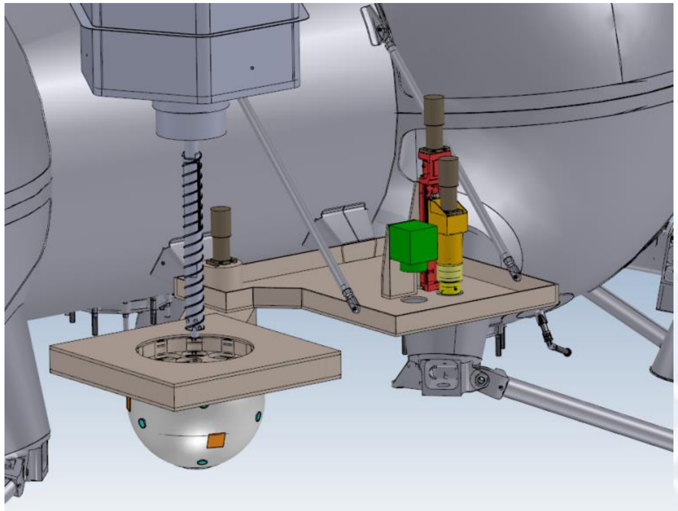




Lunar Ascent Vehicle (LAV)

Orbiting Sample Canister (OSC)



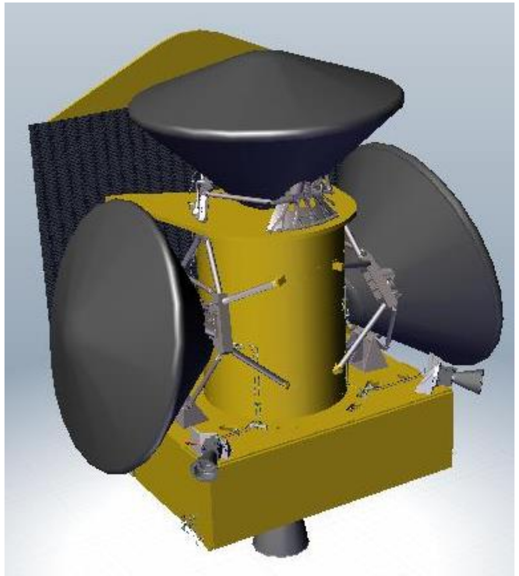


Sampling Mechanism

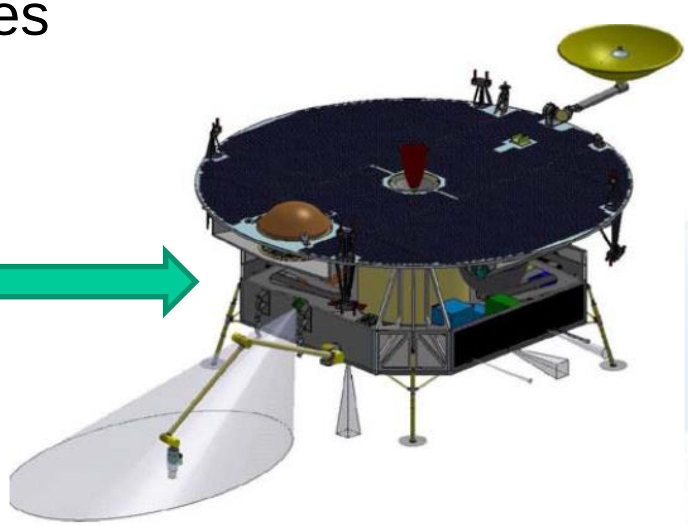
Complex space systems configurations for exploration: Mars S&R

Objective:

- Collect samples of Mars soil to perform scientific investigations in the Earth Laboratories



- Dedicated studies carried out to set up new needed technologies
  - INSPIRE : landing of three Network Science Probes (NSP) on Mars
  - PHOOTPRINT : get and return to ground a 100g sample from the Mars moon Phobos and the scientific characterization of the Martian moon



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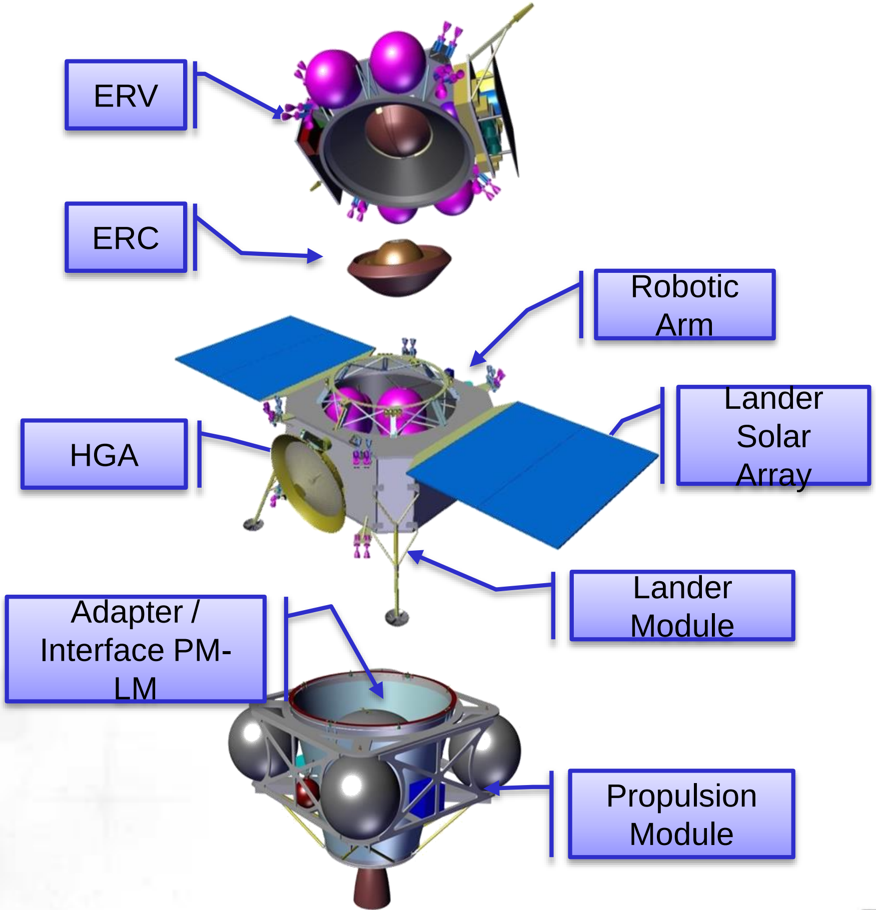
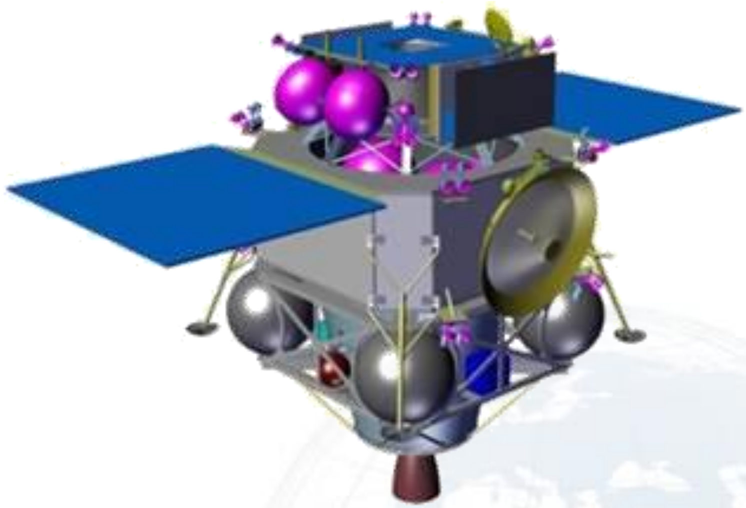
Complex space systems configurations for exploration: PhS&R

- From PHOOTPRINT to Phobos Sample and Return (ESA project) again a composite spacecraft with Propulsion module, Lander module, Earth Return Vehicle and Capsule, equipped with Robotic Arm for soil sample collection





ES Composite

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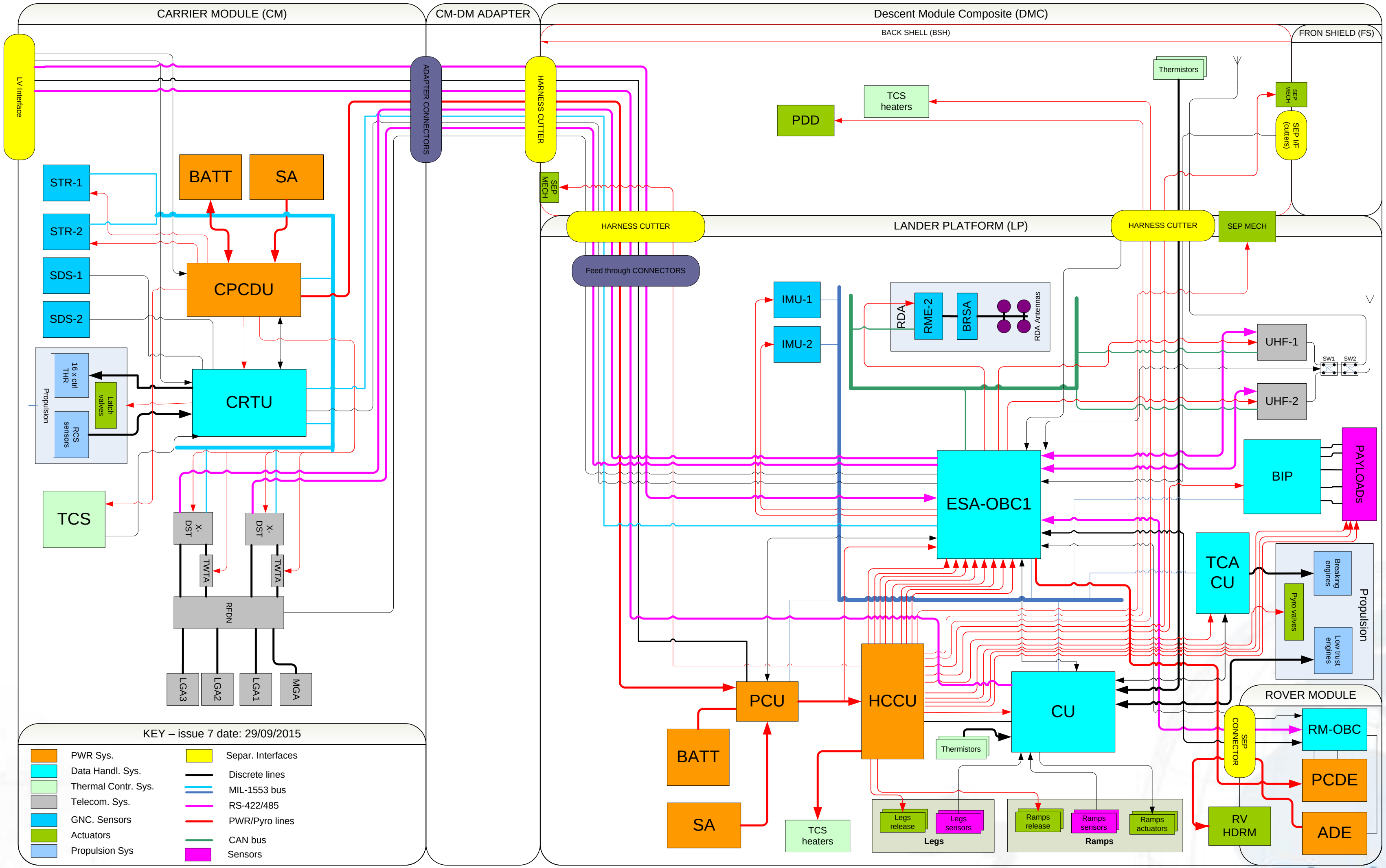
Avionics architectures for exploration missions

Avionics architecture: Distributed avionic functions - EXOMARS 2020

- The Carrier Module Remote Terminal Unit (CRTU) interfaces all CM subsystems (EPS, TCS, RF, RCS) and GNC sensors via a MIL-1553 bus and dedicated discrete lines.



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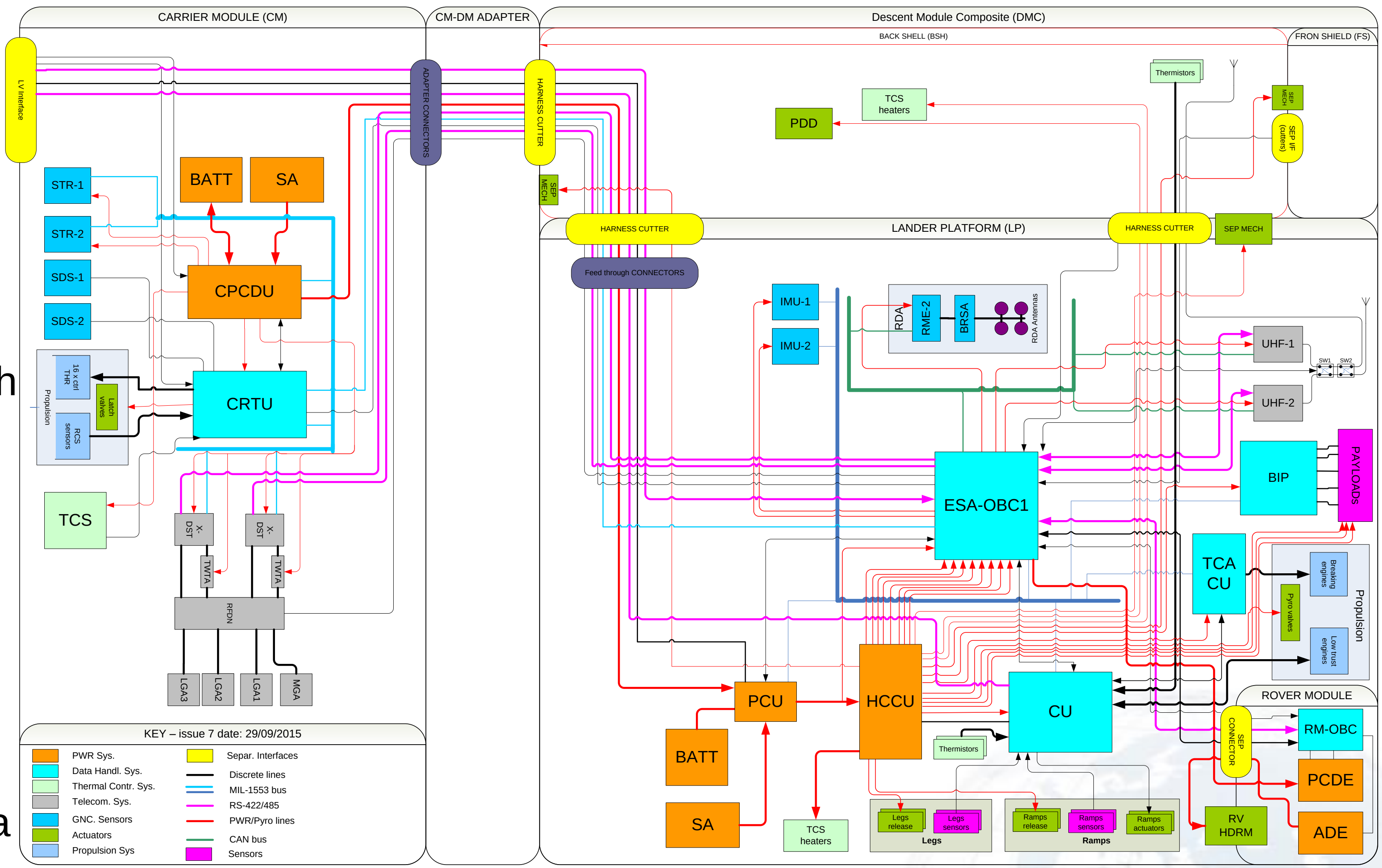
Avionics architecture: Distributed avionic functions - EXOMARS 2020

The ESA On-board computer (ESA-OBC1) hosed in the LP of the DM composite is the core element of the distributed Data Handling system. It interfaces the CRTU and the BIP of the LP, executes the GNC algorithms (of both CRUISE and EDL phases) and also interfaces the RM On Board Computer via a dedicated serial link. It actively manage all the Spacecraft Composite subsystems including DM propulsion and LP deployable mechanisms via a second Mil-1553 bus and uses a CAN bus to interface DM Radar Altimeter and UHF Transponders.



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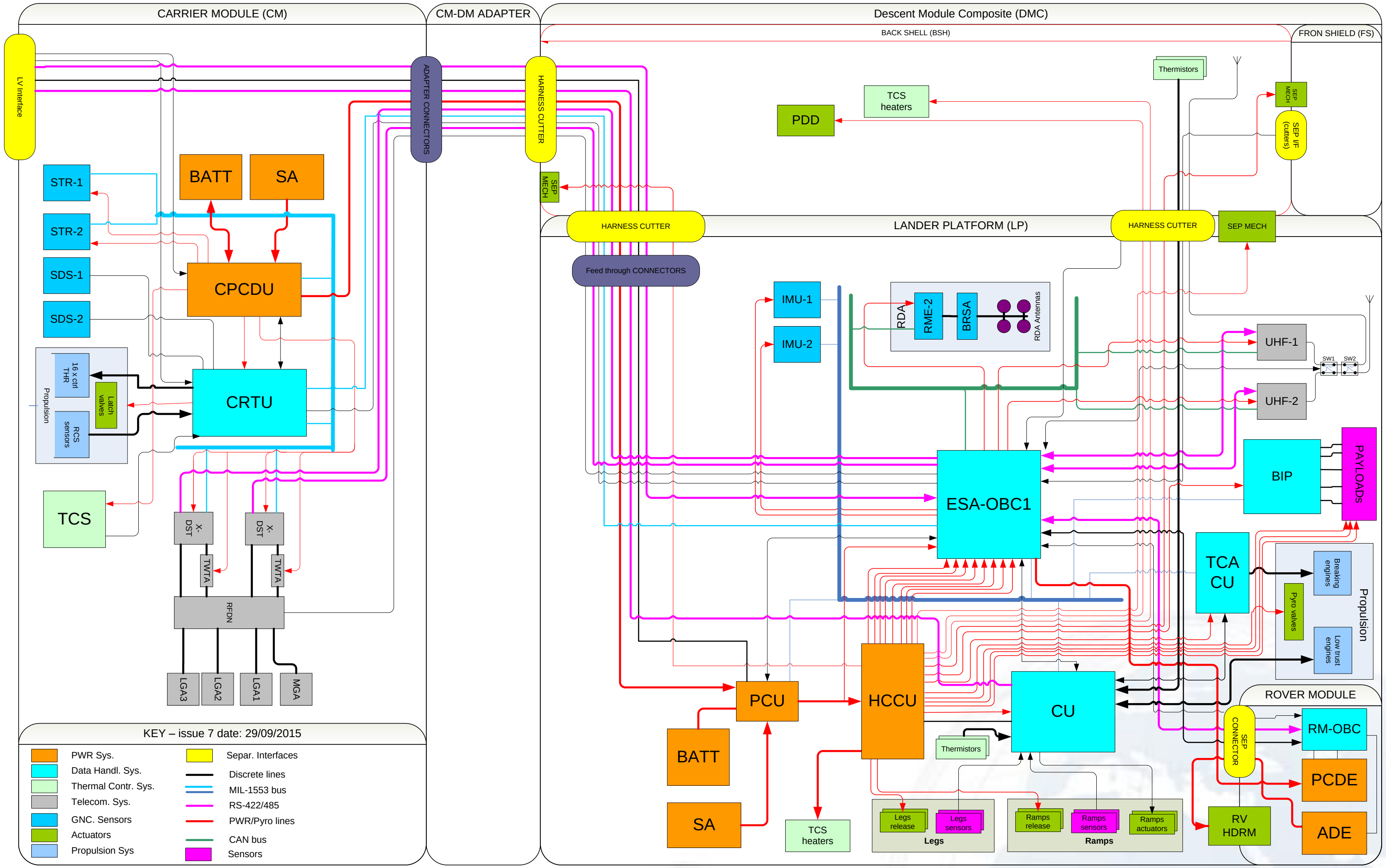
Avionics architecture: Distributed avionic functions - EXOMARS 2020

The RM avionics is quite independent because RM is active only on the Mars surface. The Rover OBC is the hearth of this module. It performs all the system functions and interfaces science instruments and other subsystems using SpaceWire links, CAN-buses, RS422 links and discrete lines.



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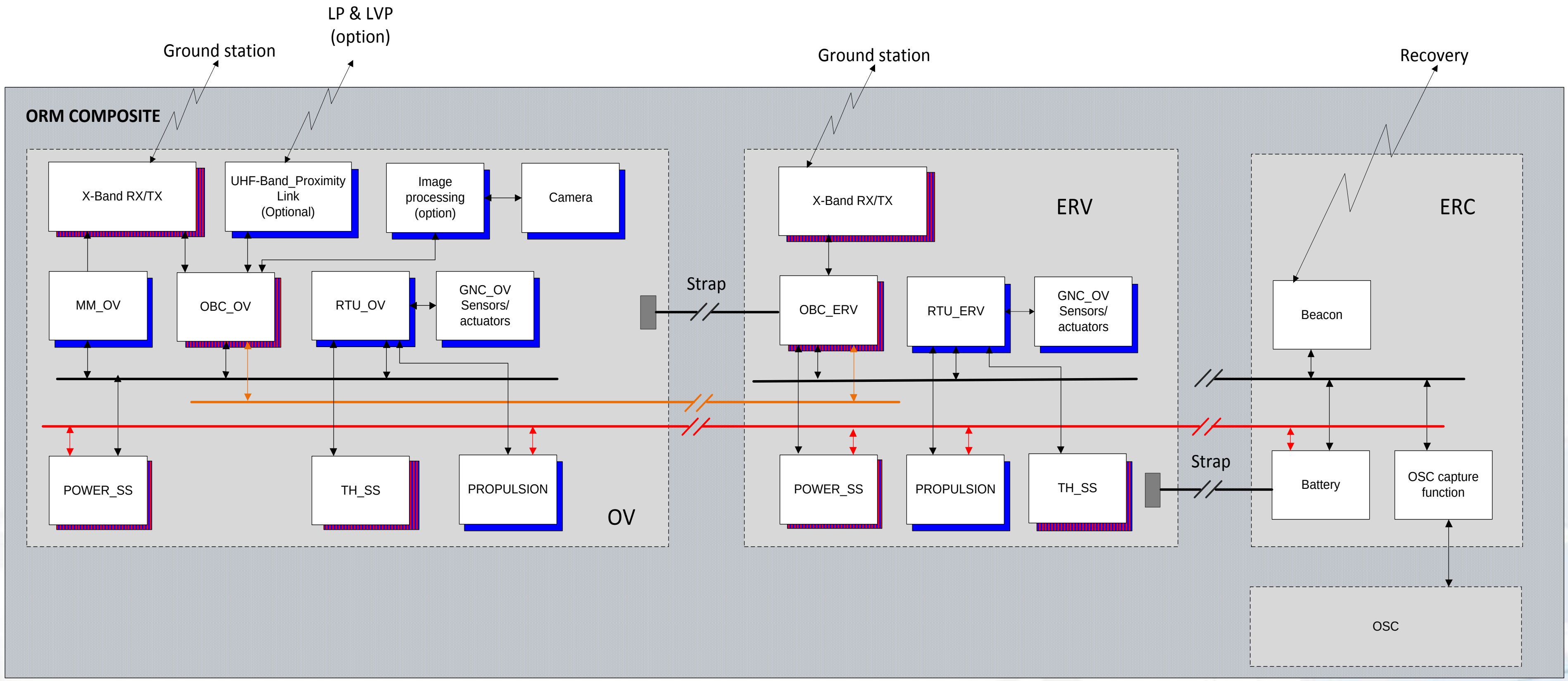
Avionics architecture: Distributed avionic functions - Lunar Polar SR

- Phase 1 (from Launch up to RdV with the LAV & OSC capture) requires the Orbiter Return Module {OV, ERV, ERC} assembly to be controlled by the OV.
  - A complete avionic configuration has to be active on the OV driven by the OV-On Board Computer in charge of interfacing the TCS, RF, EPS, propulsion and GNC subsystems. It performs all the computational task needed for Rendezvous and capture based on Camera



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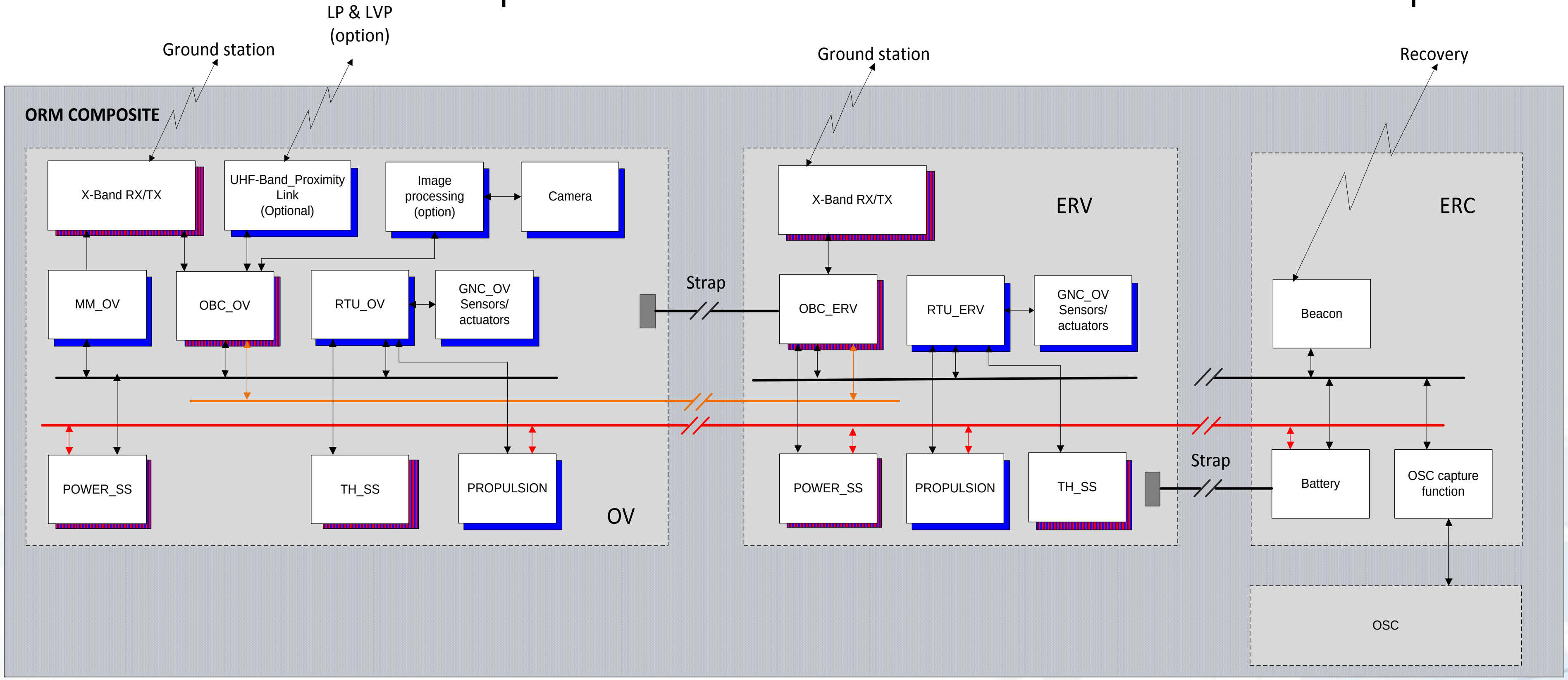
Avionics architecture: Distributed avionic functions - Lunar Polar SR

- Phase 2 (from OSC capture to Earth approach) the ERV {ERV, ERC, OSC} assembly separates from the OV and return to Earth. The OV remains as self-standing Lunar Orbiter.
  - The ERV avionic configuration shall include all the functions. An ERV-On Board Computer controls the assembly functions (Thermal, Propulsion, Power, GNC) and interface the OV-OBC via a dedicated inter-processor link needed to initalise the ERV before separation



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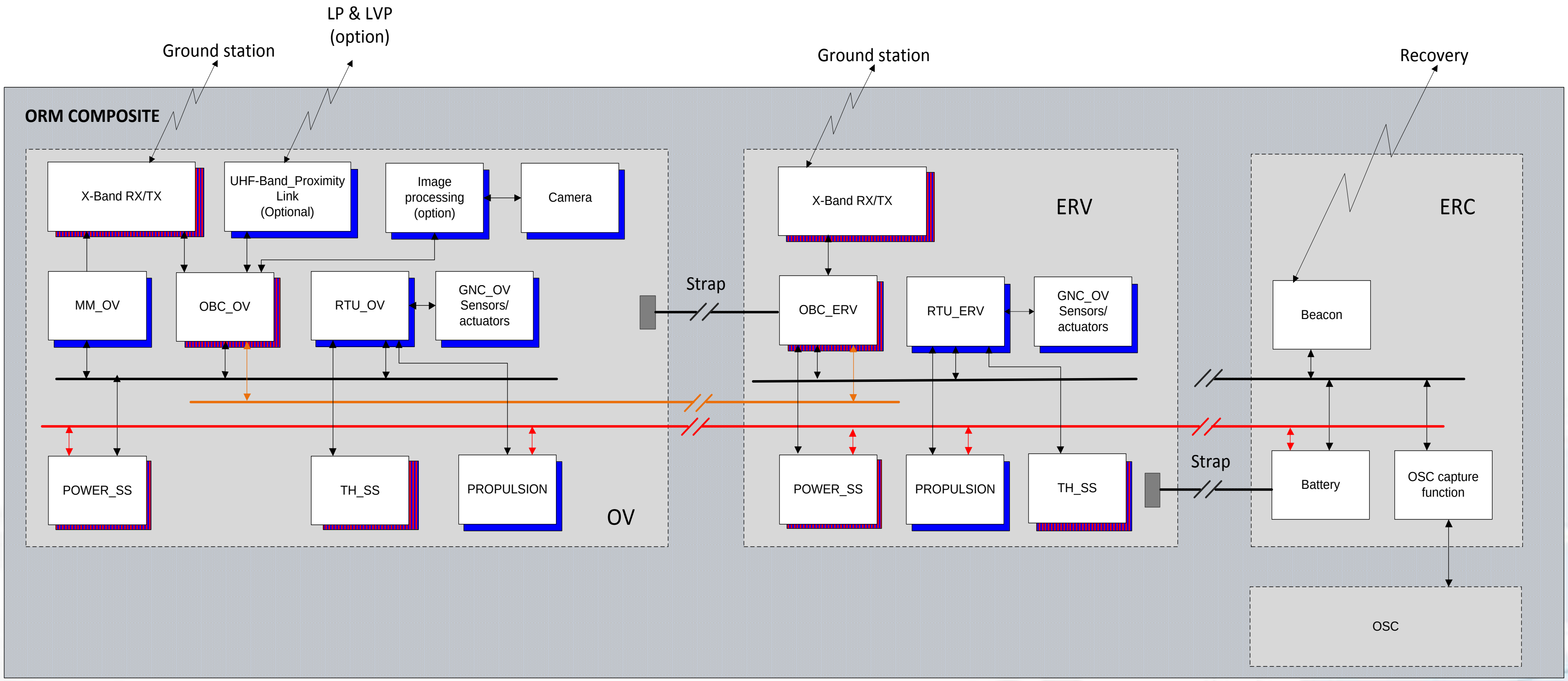
Avionics architecture: Distributed avionic functions - Lunar Polar SR

- Phase 3 (from Earth re-entry to Landing) the ERC is equipped only with a beacon and battery for ground rescue



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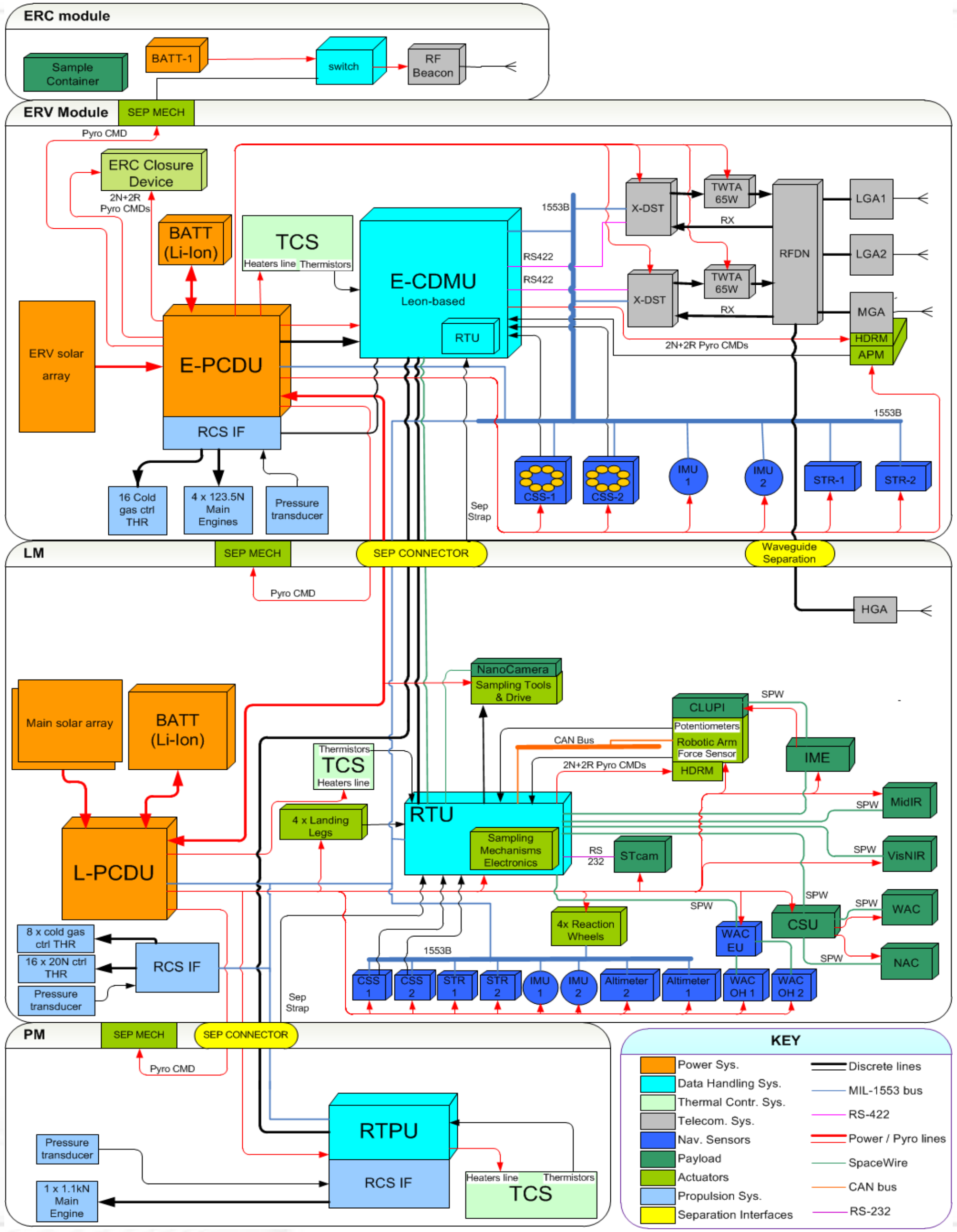
Avionics architecture: Distributed avionic functions - PhSR



PhSR Mission scenario foresees that Lander Module remains on Phobos.

Avionic configuration can be based on a central On Board Computer

- Propulsion Module (PM) function is carried out by RTPU interfacing TCS and RCS subsystems and directly driven by the central OBC (E-CDMU)
- Lander Module (LM) hosts EPS, TCS, RCS functions, GNC sensors, robotic harm and payloads. They could be managed by an RTU directly linked to the main computer. Accurate design needed for the communication load on the system bus taking in to account operations.

  HGA is integrated on the LM because not needed during the return phase.
- Earth Return Vehicle hosts the main computer running the OBSW and controlling TCS, EPS, RCS, GNC and RF subsystems
- ERC is equipped only with a beacon and battery for ground rescue of the sample container

Avionics architecture: Key requirements

- Spacecraft composite mass compatible with the launcher capability (minimise mass)
- Power consumption minimised
- Reliable communication system is needed
  - Significant data volume return for science and lander operations (high data rate link)
  - Direct To Earth communication at least for command uplink
  - Data Relay handling and operations (Orbiter - Lander visibility)
  - Communication during EDL phases
- Handling of separation between modules of the composite spacecraft
- Managing of subsystems for Rendezvous and Capture and for EDL (LIDAR, radar, altimeter, cameras)
- Handling of subsystems for soil sampling (robotics harm, drill)
- Handling of mechanism for sample storage and transportation
- High storage capability of scientific data (Mass Memory)
- Capability to manage communication busses, I/O interface and direct command
- Adequate computational capability of the On Board Computer
- Implement protections against radiation environment
- **High level of autonomy during all mission phases**

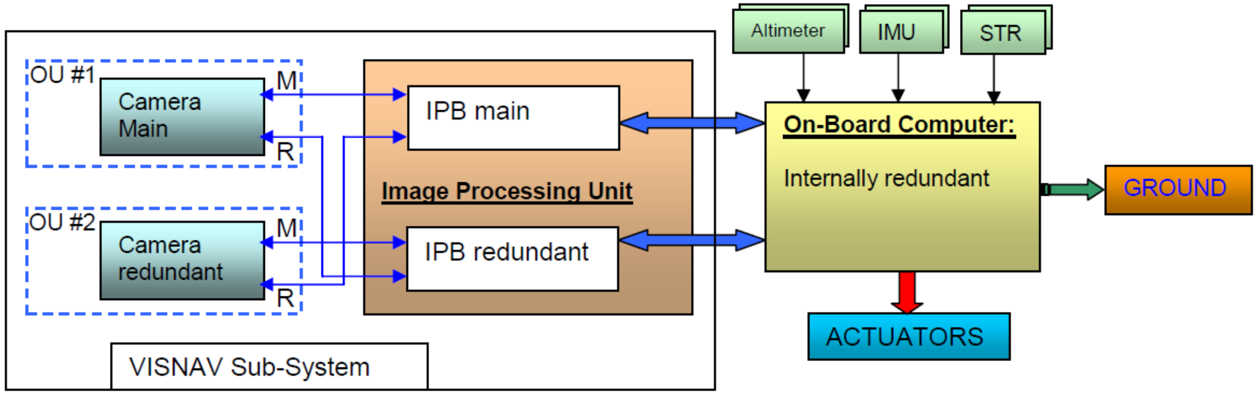
New Technologies

New Technologies: Vision Based Navigation

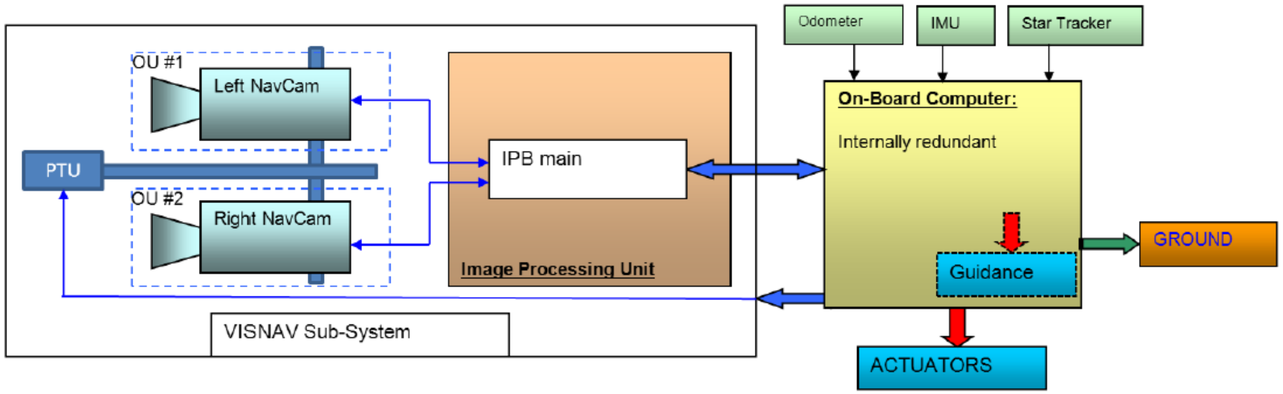
- Autonomy improvement for Planet Exploration can be obtained with Vision Based Navigation technologies
- VBNAV systems based on cameras are configurable according to the mission profile
  - NAC can be used for interplanetary navigation
  - NAC and WAC can be used for RV & Capture
  - WAC camera (50deg FOV) can be used for EDL while NAC is preferred for Hazard Detection
  - Rover surface exploration requires Navigation cameras, Localization Cameras and Hazard cameras with different FOVs
- Cameras satisfy low mass (≈ 0,5Kg) and low power (≈ 6W) requirements and can be made more robust implementing autonomous features like definition of integration time, bad pixel correction, Non Uniformity Calibration, Windowing for ROI acquisition
- VBNAV requires Image Processing algorithms and Navigation filters computationally demanding and therefore adequate HW platforms that are not available as space qualified processor. For mission phases running at high frequency (EDL @10Hz) FPGA implementation is required.
- VBNAV systems require communication busses at high data rate

New Technologies: Vision Based Navigation

- VisNav-EM-1 and SAGE, ESA studies led by TAS-I, have studied and implemented by HW demonstrators a general architecture of a vision based navigation system suitable for both EDL (Mars and Moon) and for Surface Mobility (Moon) scenarios.



EDL



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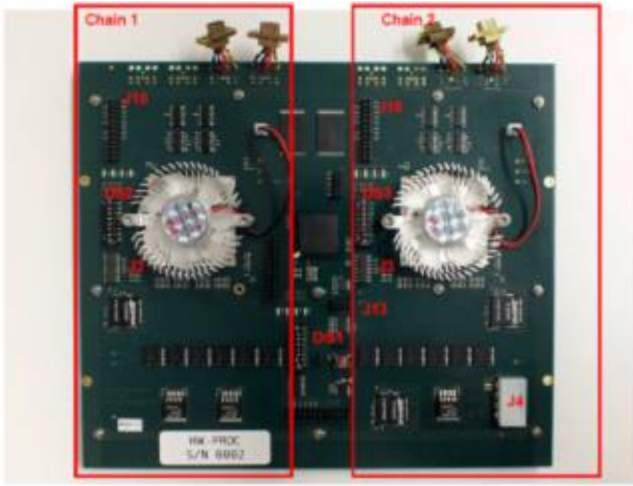
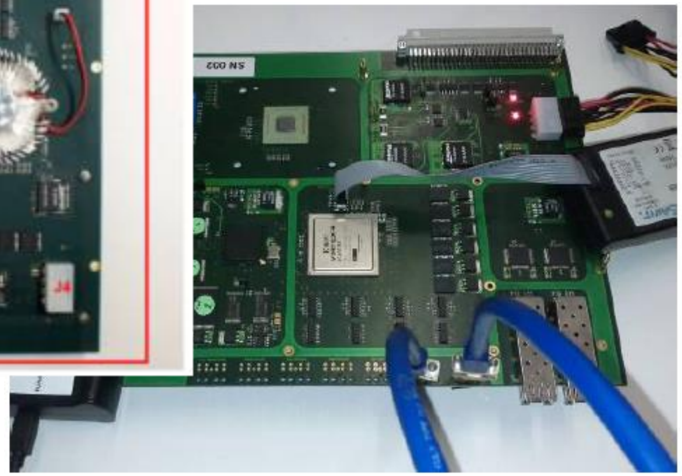
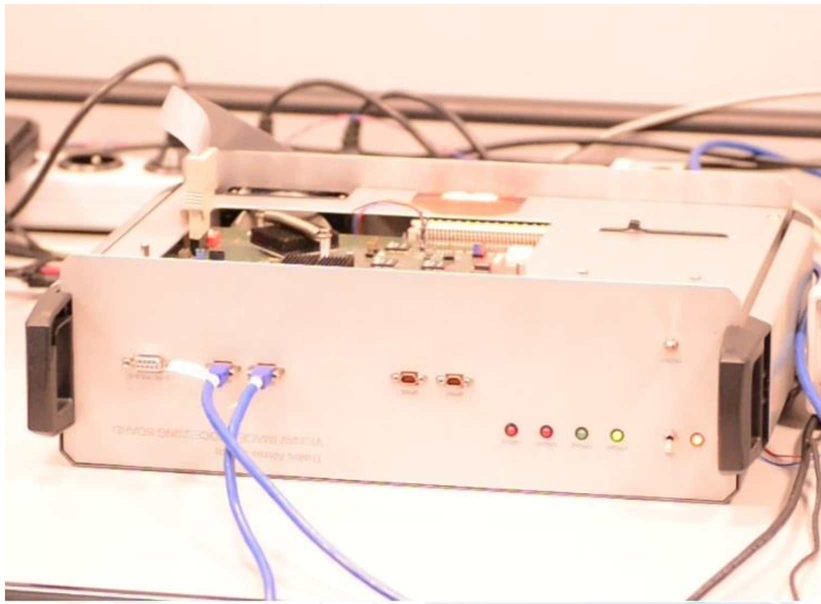
- Components of the VISNAV sub-system are Camera and Image Processing Board linked each other and with the On Board Computer via SpaceWire lines.

New Technologies: Vision Based Navigation

- IPB is an HW platform composed by two elements interfacing each other via SpW links:
  - A dedicated HW processing section, implementing high density reprogrammable FPGAs (Xilinx Virtex-5 XC5VFX130T), housing mainly the HW part of the Image Processing. Two identical input channels are implemented
  - A general purpose High Performance Processing Module (TASI HPPM based on PPC7448@1GHz) to run the Software part of Image Processing
- IPB HW section interfaces Camera and OBC by a SpW router embedded in each FPGA. SpW routher is the kernel of the communication in the VisNav System



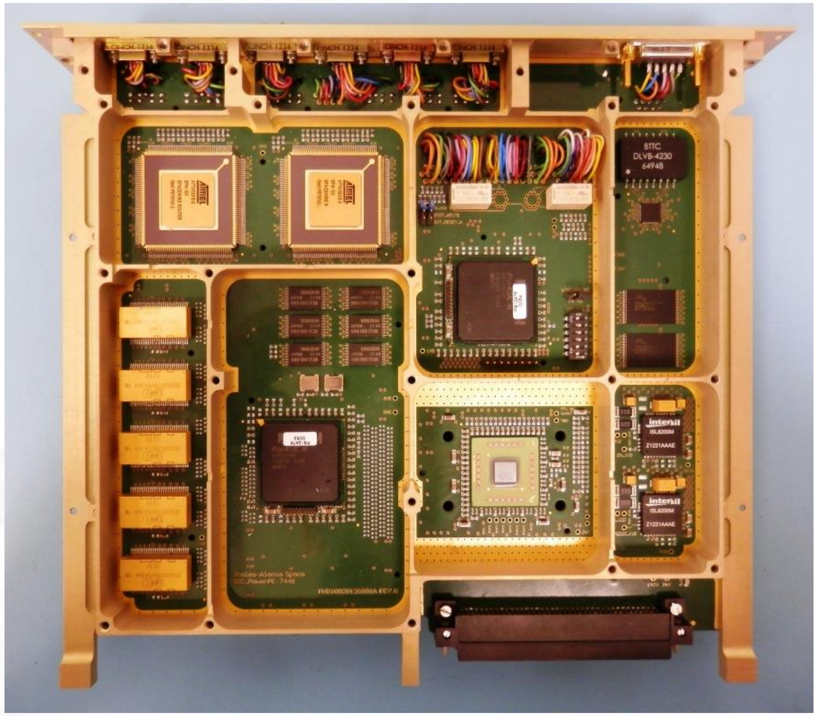




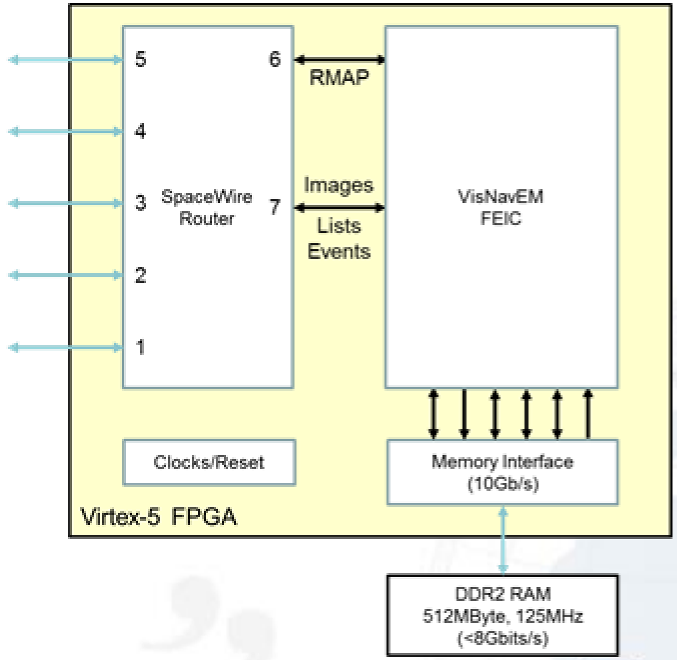
New Technologies: Vision Based Navigation - COTS platform

High Performance Processing Module is based on COTS processor (PPC7448). It is evolving towards a new Single Board Computer to be integrated in the Lightning Imager instruments of the Meteosat Third Generation Imaging (MTG-I) satellites

FPGA Virtex 5 has Space – grade version (Virtex-5QV) and is reconfigurable and adequate for intensive processing. In Visnav it has been programmed with FEIC algorithm (by University of Dundee) used for relative navigation running @10 Hz and with Image filters and SpW Packet decoder

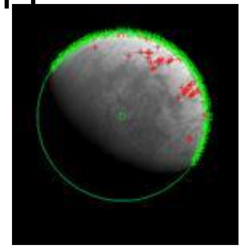


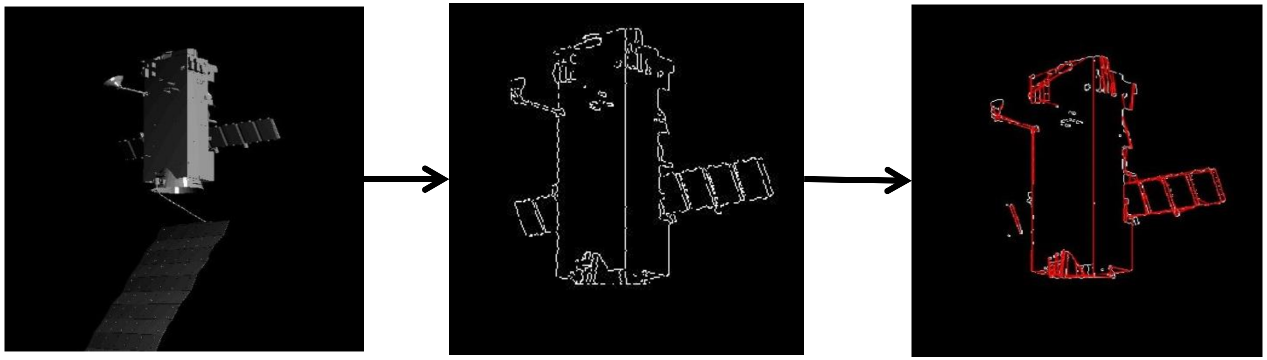
FPGA architecture



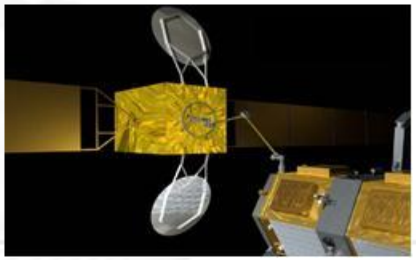
New Technologies: Vision Based Navigation - rendez-vous

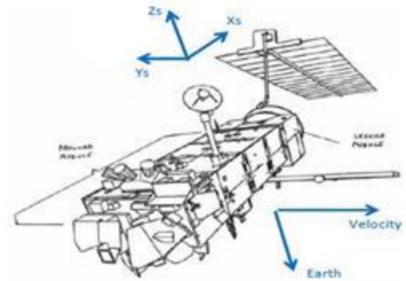
- Multiple activities enable autonomous image processing for future rendez-vous applications
  - Asteroids simulation, multispectral imaging
  - IP for navigation with moons (<1/10 pixels accuracy)
  - IP for closed-range autonomous relative navigation
  - Efficient guidance, navigation & control algorithms





- Gripper & arm development & verification in closed-loop dynamic test
  - Docking mission in Earth Orbit with Non-cooperative Spacecraft
  - Quick grip with the robotic arm to capture the debris
  - Robotic arm joints damping and reorientation
  - Tight grip with a 2nd gripper to ensure a very rigid stack
  - Collaboration with many companies, universities and research centres





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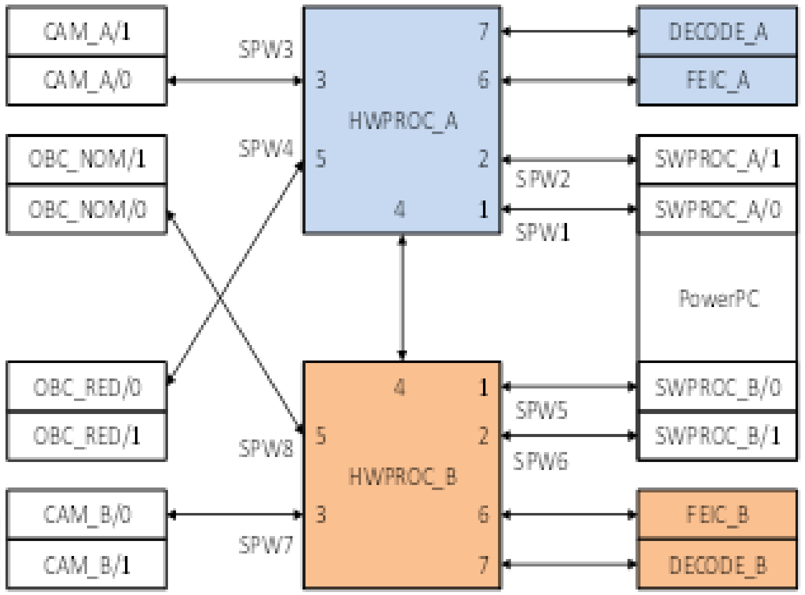
Challenges and opportunities

Challenges and opportunities

- The VBNAV System can be configured according to the mission need because based on FPGA and powerful COTS processor. Also Camera can be properly adapted to the mission requirement selecting the adequate FOV and settings.
- FPGA (programmable) can be configured with VHDL code of computationally demanding algorithms to be executed at high frequency
- Sensors like LIDAR, Altimeter, Radar can interface directly the FPGA of the IPB which can execute part of the data processing or which can pass the measurement to the Processor section of the IPB.
- Furthermore FPGA can become the communication bridge of the system embedding IP cores of the needed interface bus or links. It can be configured accordingly taking into account that it shall be fully programmable

SPaceWire Router in VisNav-EM-1



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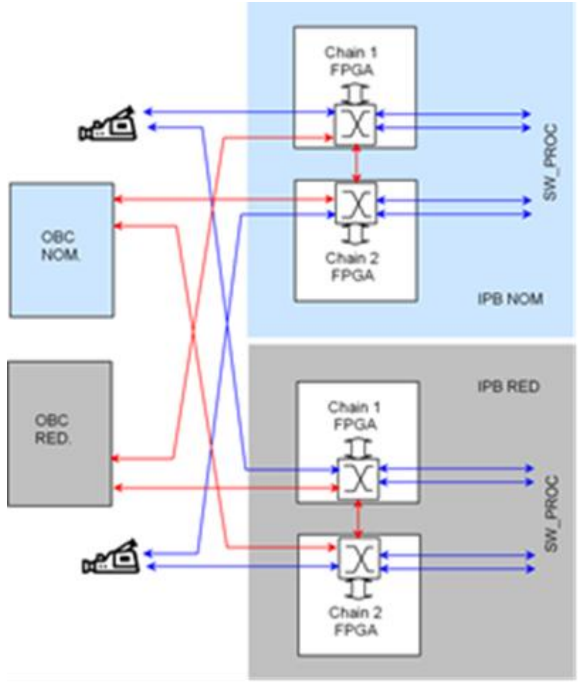
Challenges and opportunities

- OBC remains the space qualified computer in charge of system and safe mode management. It interacts with the IPB reducing exchange of information on the system bus.
- Parallel processing is possible on OBC, IPB processor and FPGA in mission phases where high computational performance is required.
- An architecture based on IPB + OBC studied for EDL and Surface Mobility Navigation can be extended to Active Debris Removal mission
  - Capture phase of a non-cooperative target can require high data rate of Image acquisition and processing in input to the GNC
- Applicability can be also studied in payloads processing images for Earth Observation programs



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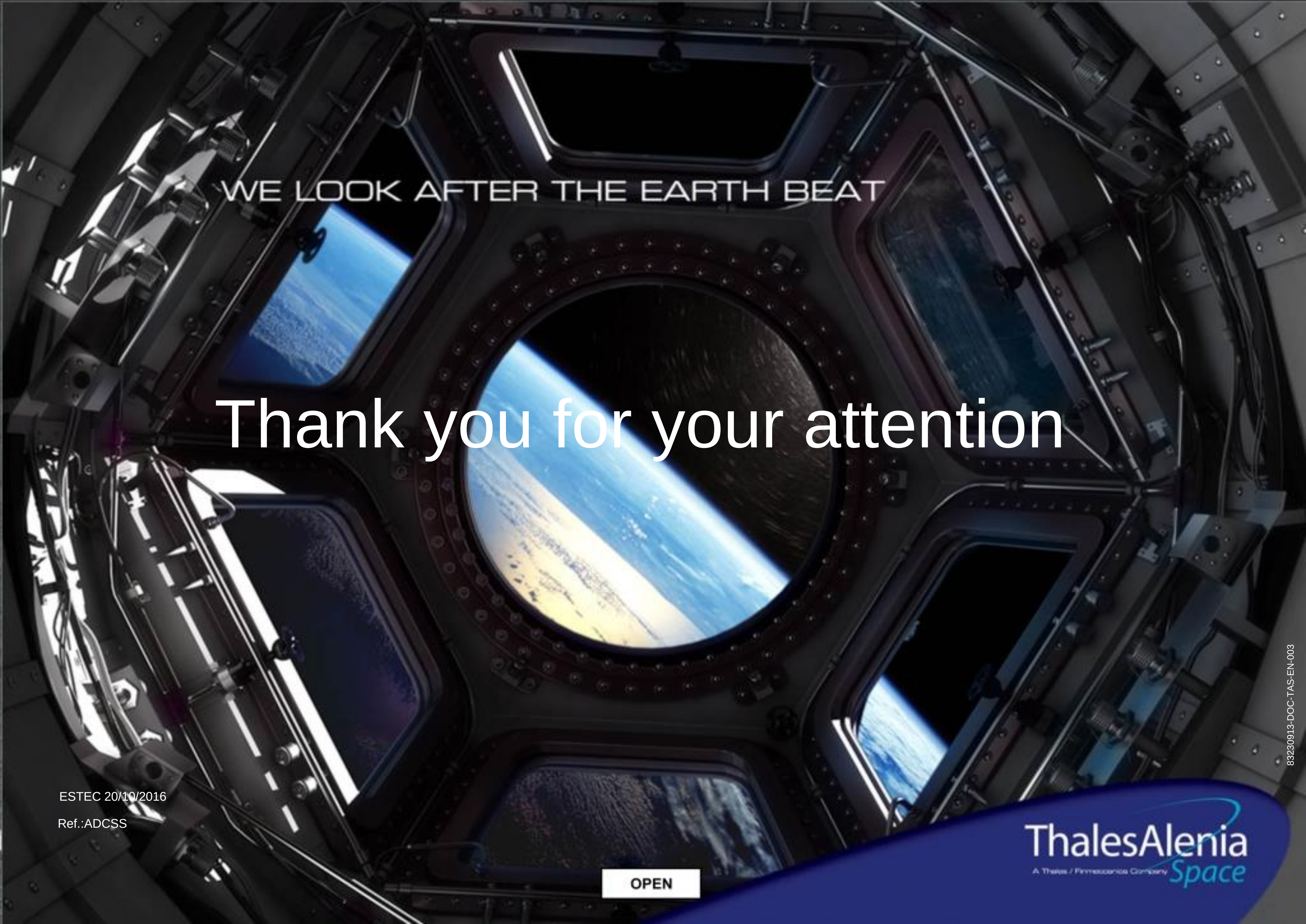
Conclusions

Conclusions

- Planet exploration requires complex composite spacecraft. Examples have been presented of Exomars 2020, Lunar Sample Return and Phobos sample and return
- For each Composite Spacecraft configuration the avionic architecture has been presented pointing out the main distributed functionalities
- From the presented Exploration missions key requirements have been derived with special attention to the new sensors/subsystem that are requested to achieve high level of mission autonomy
- New technology that can be considered needed for the Planet exploration is the Vision Based Navigation. VisNav-EM-1 system design has been presented. It is based on Camera and Image Processing Board
- Challenges and opportunities of the VISNAV system have been described identifying possible extension of the same configuration to different exploration scenarios.



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