Technology Roadmaps for the Moon and Mars Exploration

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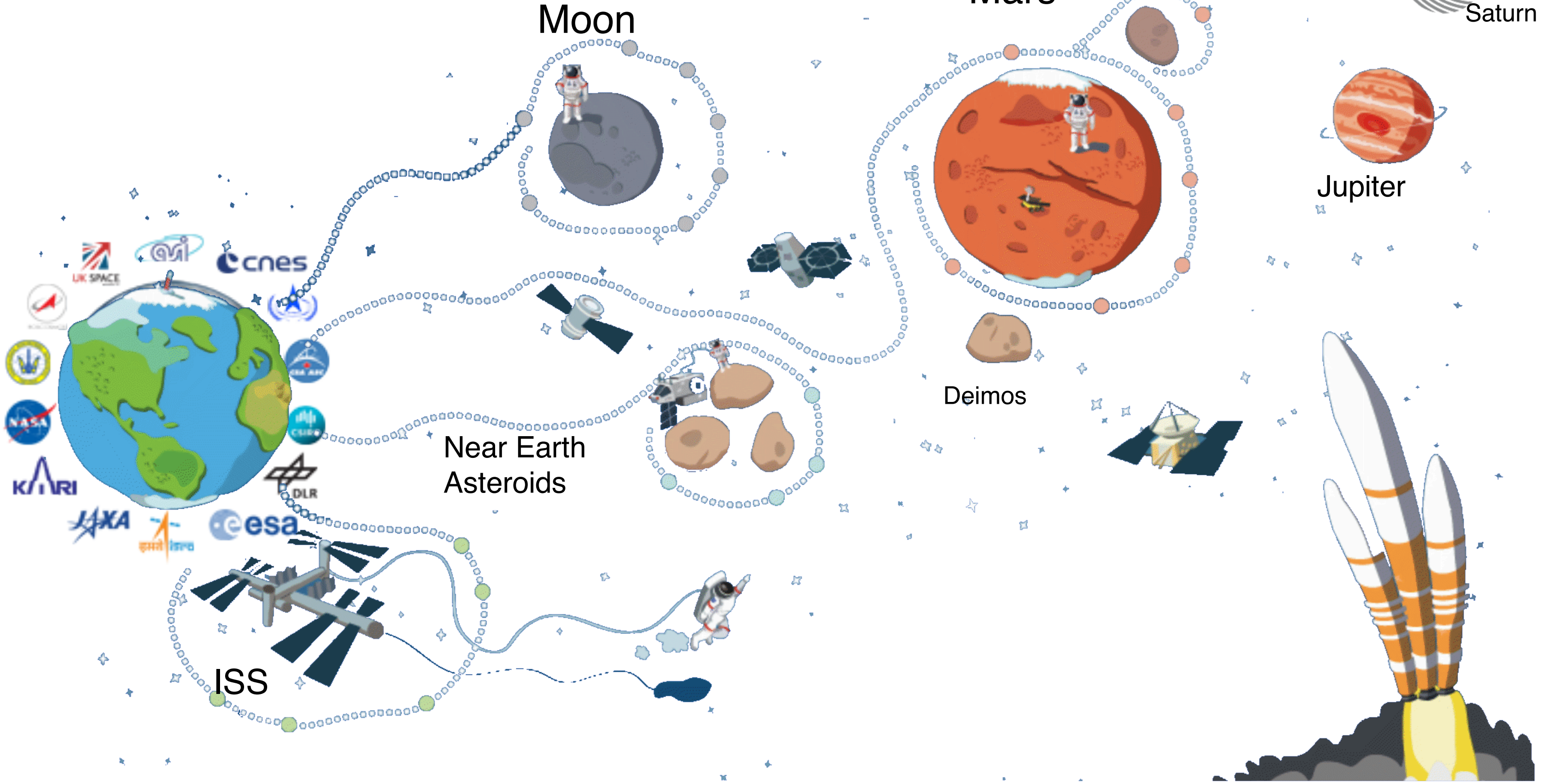
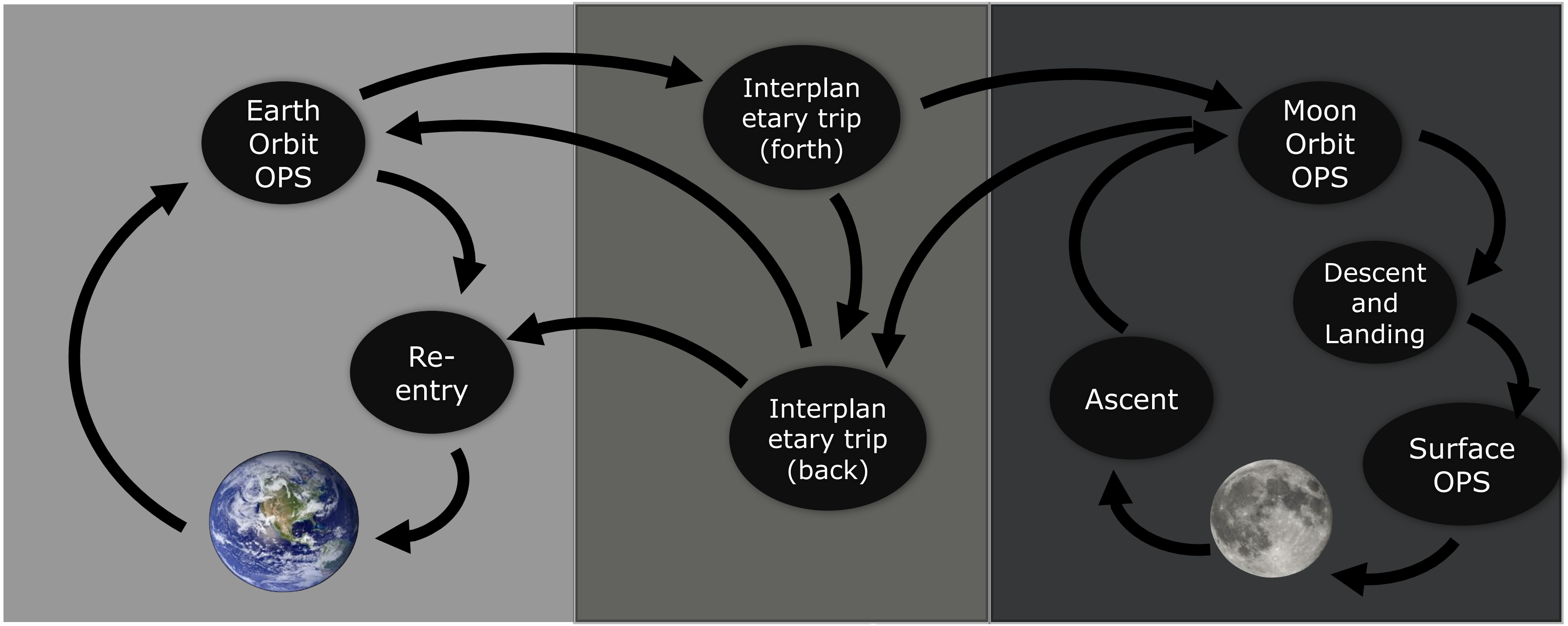
GLOBAL EXPLORATION ROADMAP



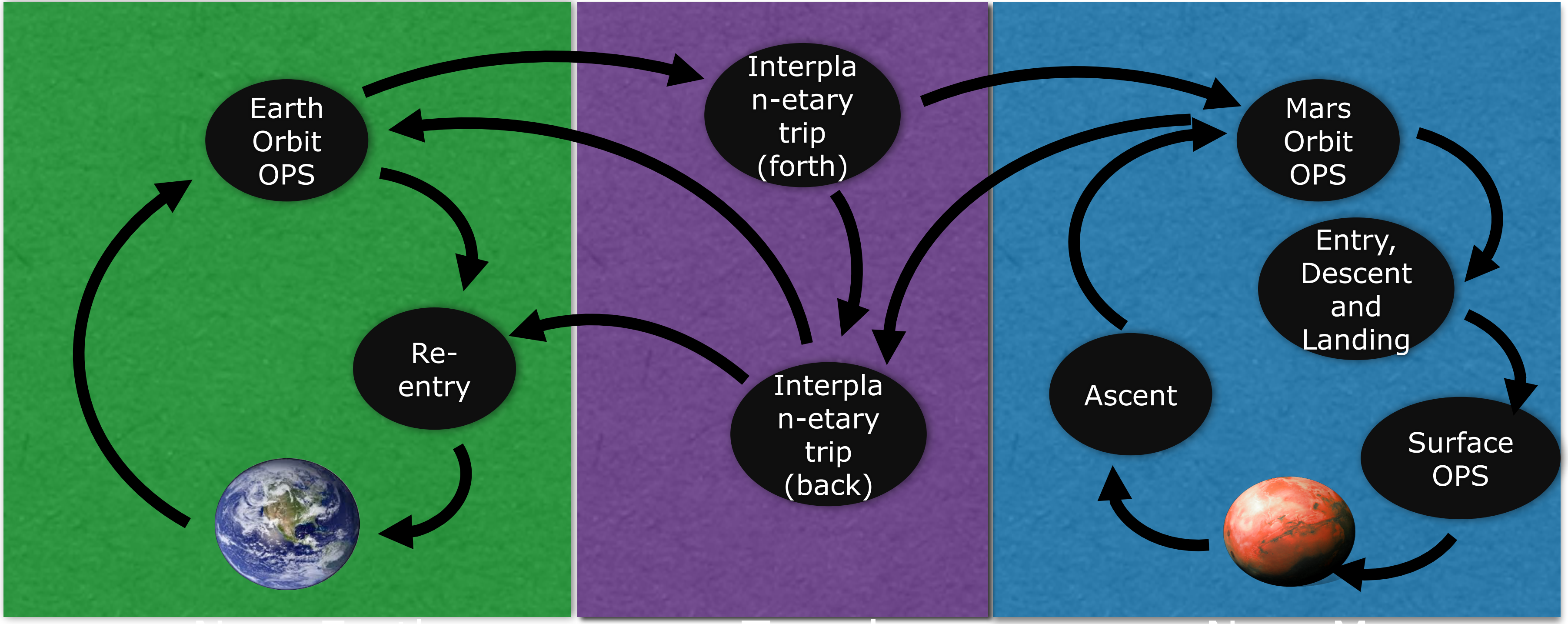
EXPLORATION TECHNOLOGY ROADMAPS BY TEC

- ESA initiated in 2013, under leadership of the Directorate for Technical and Quality Management, the **development** of its technology **roadmaps** for space exploration
- Two iterations of these roadmaps have been developed so far, one in 2013 and an updated version in 2017
- This handout has the **target** to particularise the exploration **technology roadmaps** for the exploration of Moon and Mars

OPERATIONAL CAPABILITIES FOR THE MOON EXPLORATION



OPERATIONAL CAPABILITIES FOR THE MARS EXPLORATION



FUNDING SOURCES FOR EXPLORATION TECHNOLOGY

TRP and GSTP

Technologies for exclusive use of the Moon and Mars exploration or with multi-domain application

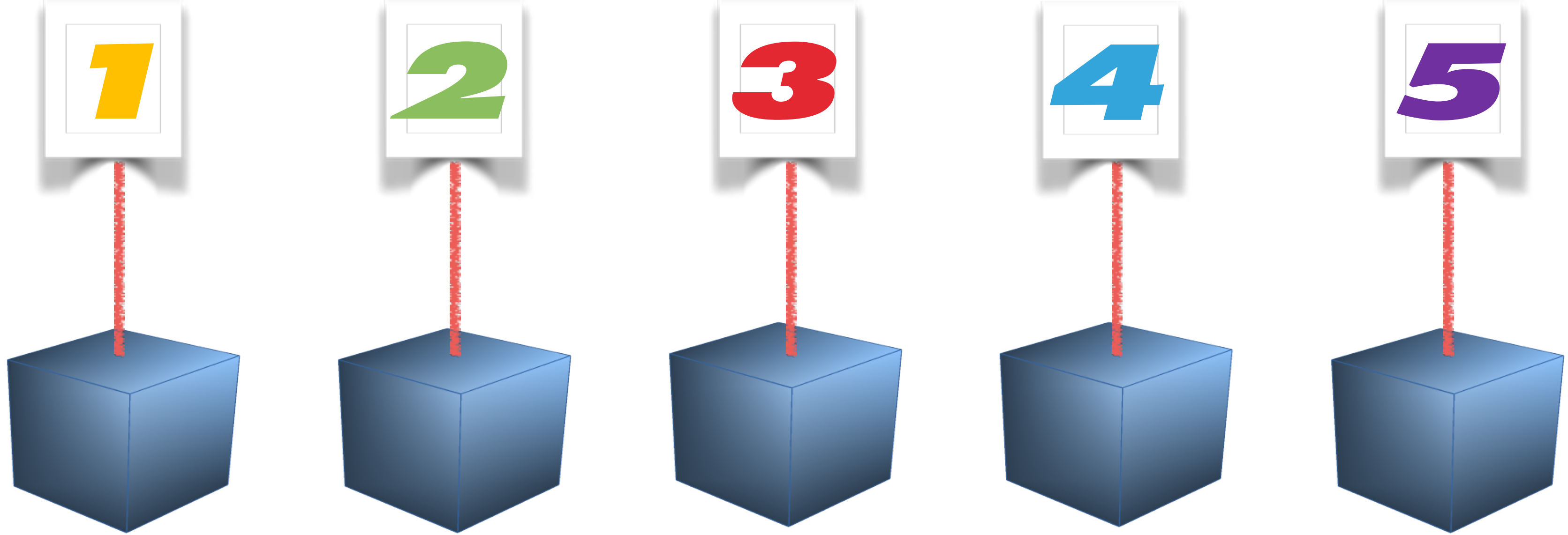
Programs approved at CM2016

ExPeRT, Luna-Resource Lander, SciSpacE, …

Other ESA programs outside Exploration

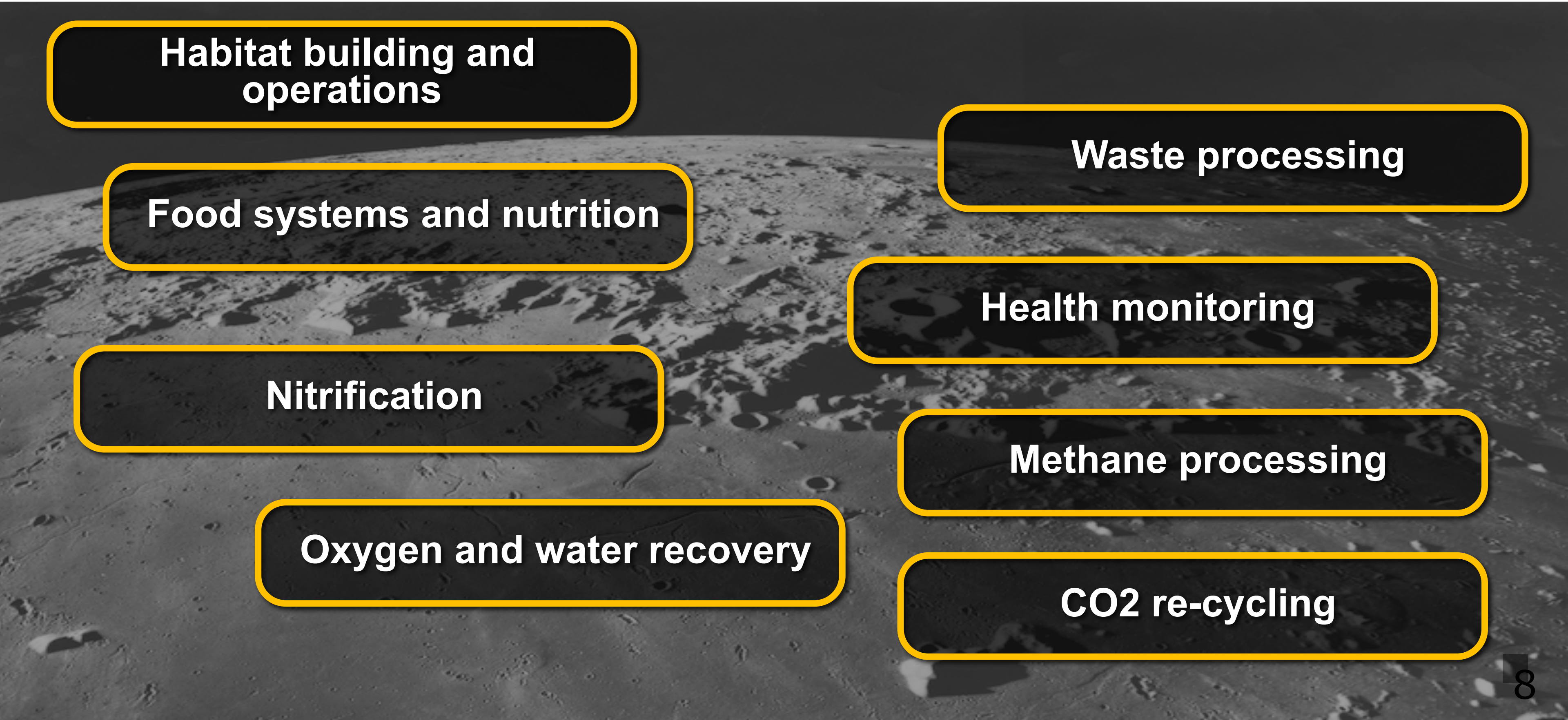
Technologies with an application potential also for the Moon and Mars exploration

TECHNOLOGY AXES FOR THE EXPLORATION

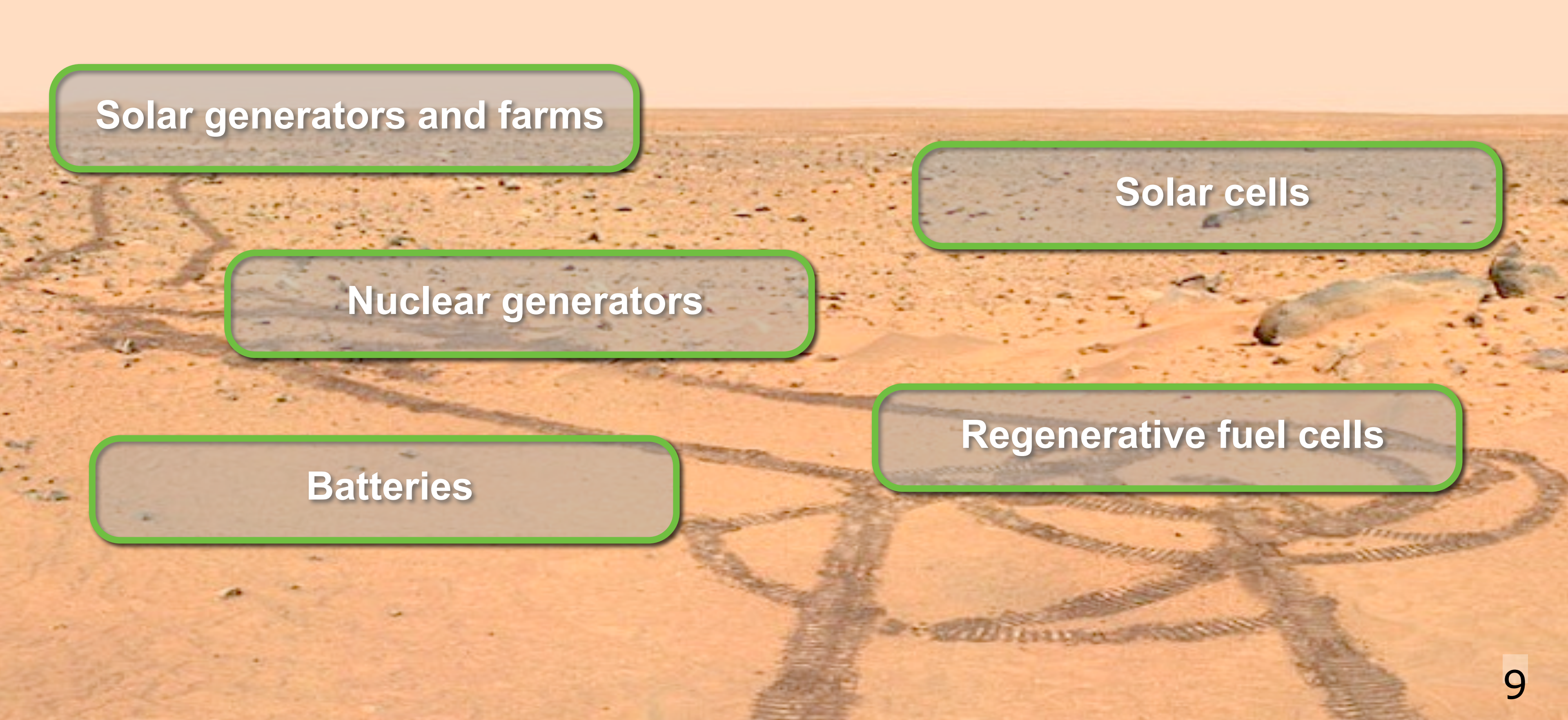


1. Life support and habitats
2. Energy production and storage
3. Robotics and tele-operations
4. Guidance, Navigation, and Control
5. Communications

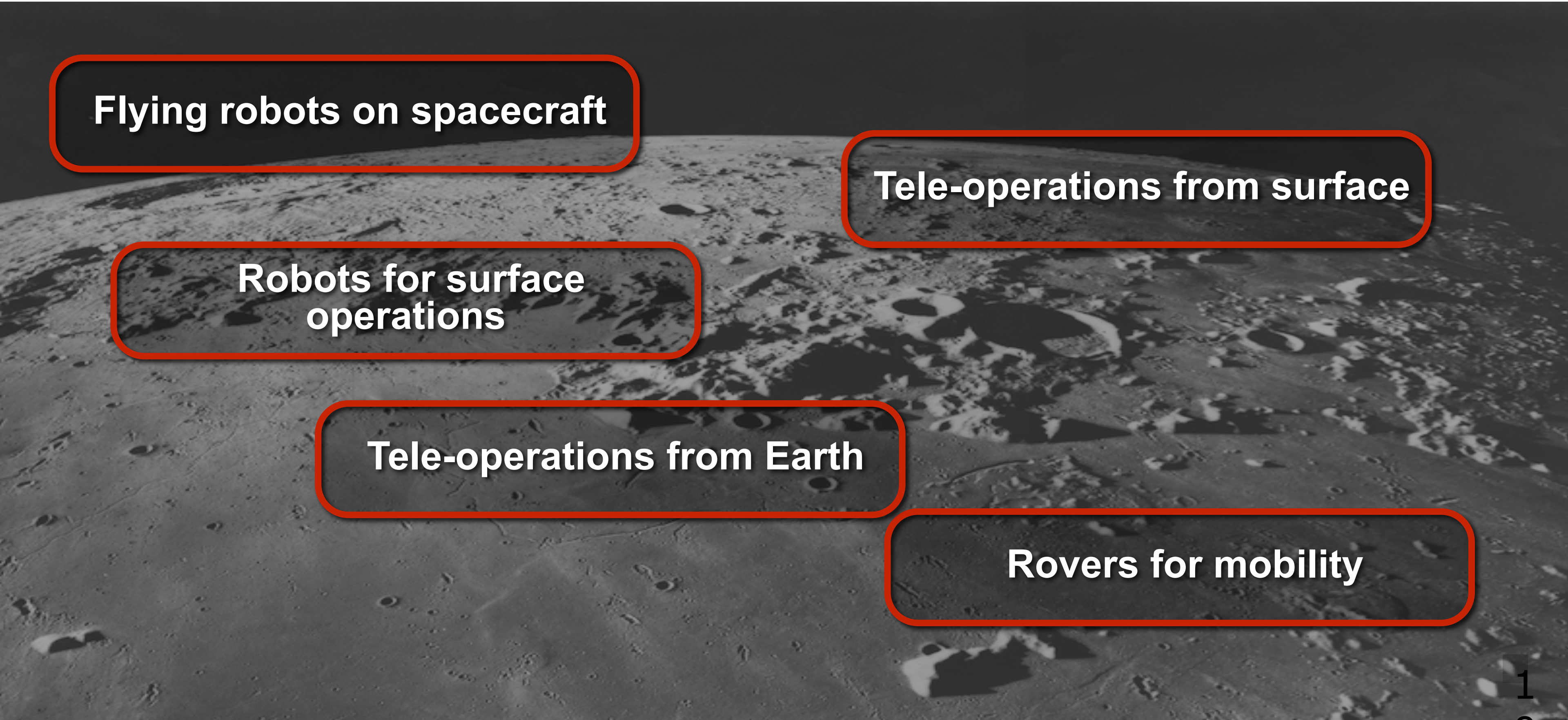
LIFE SUPPORT AND HABITATS



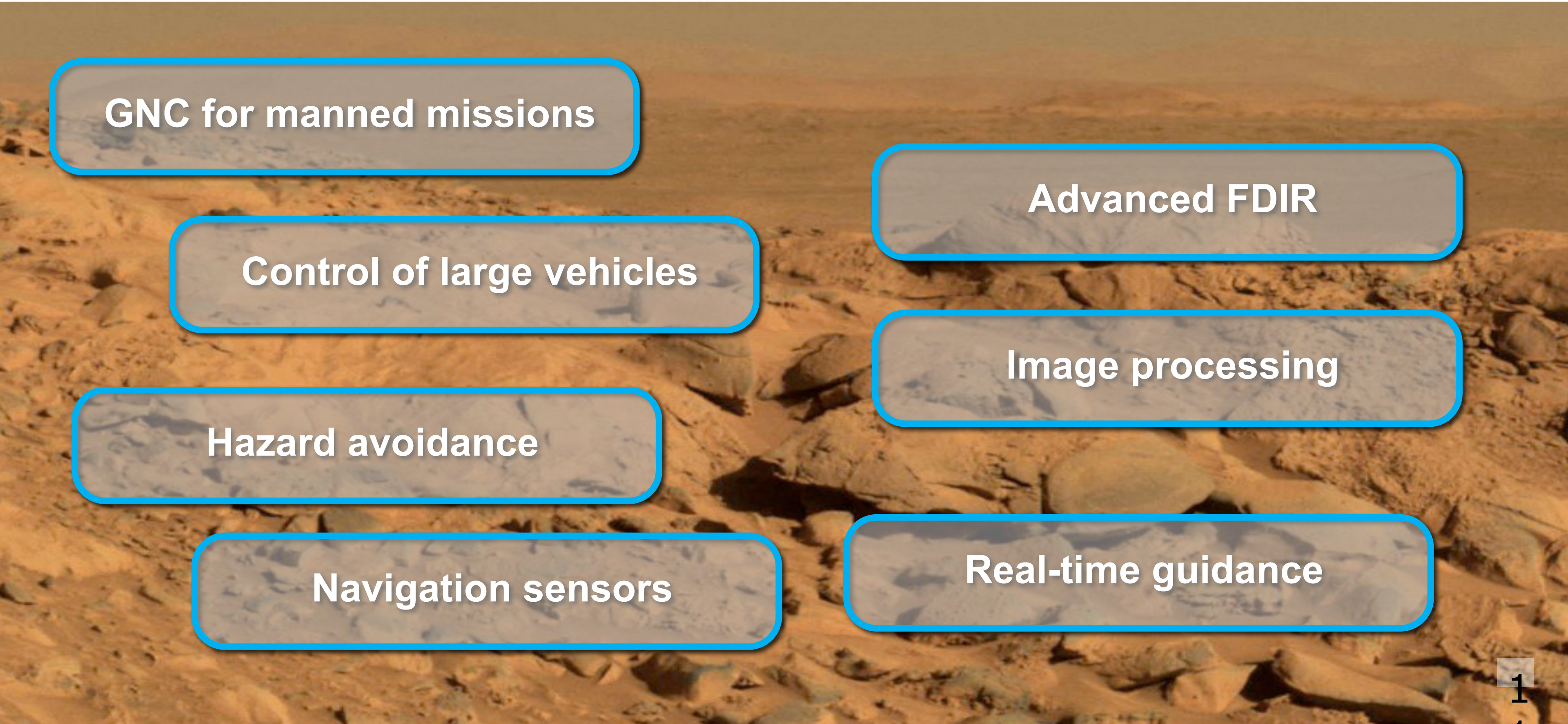
ENERGY PRODUCTION AND STORAGE



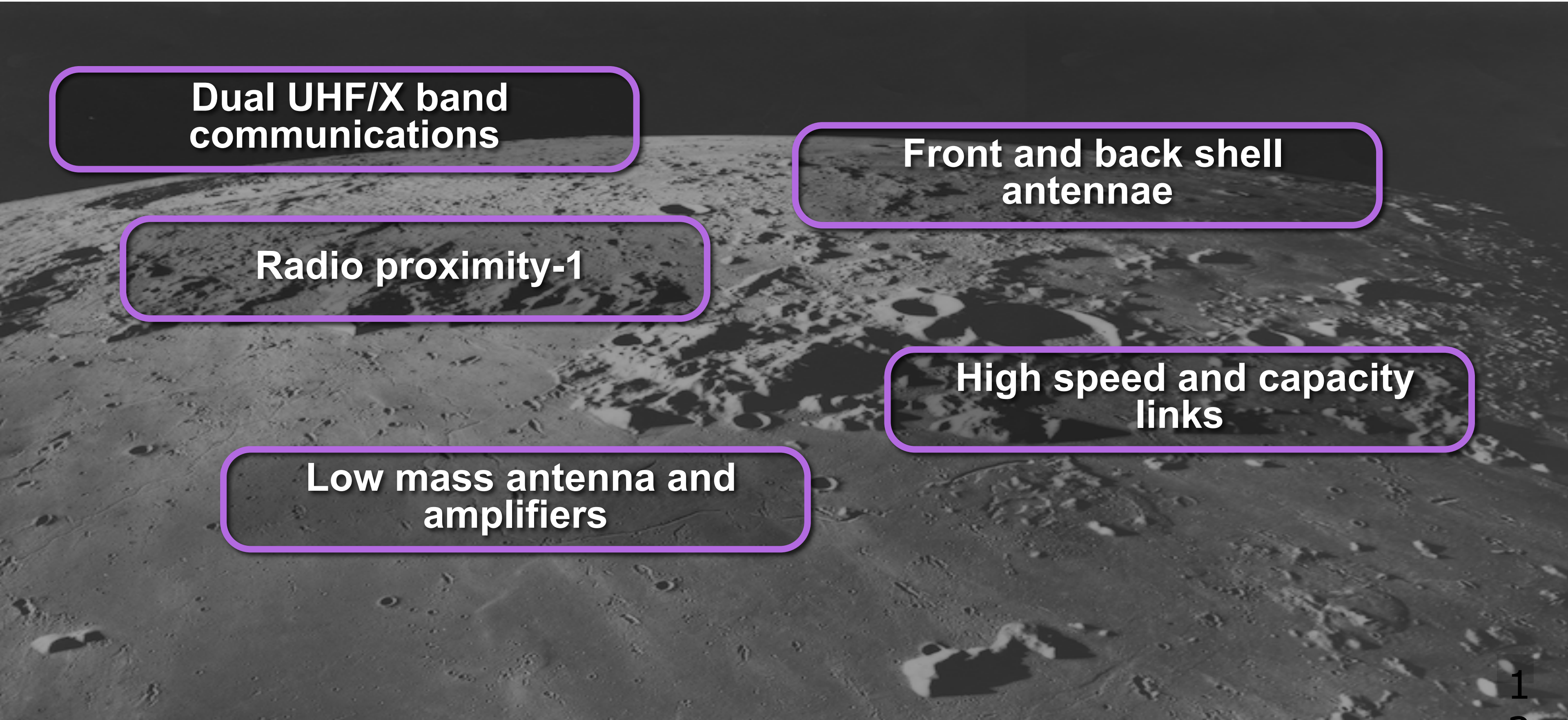
ROBOTICS AND TELE-OPERATIONS



GUIDANCE, NAVIGATION AND CONTROL



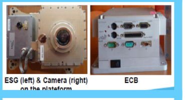
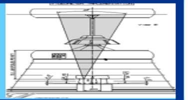
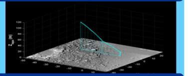
COMMUNICATIONS



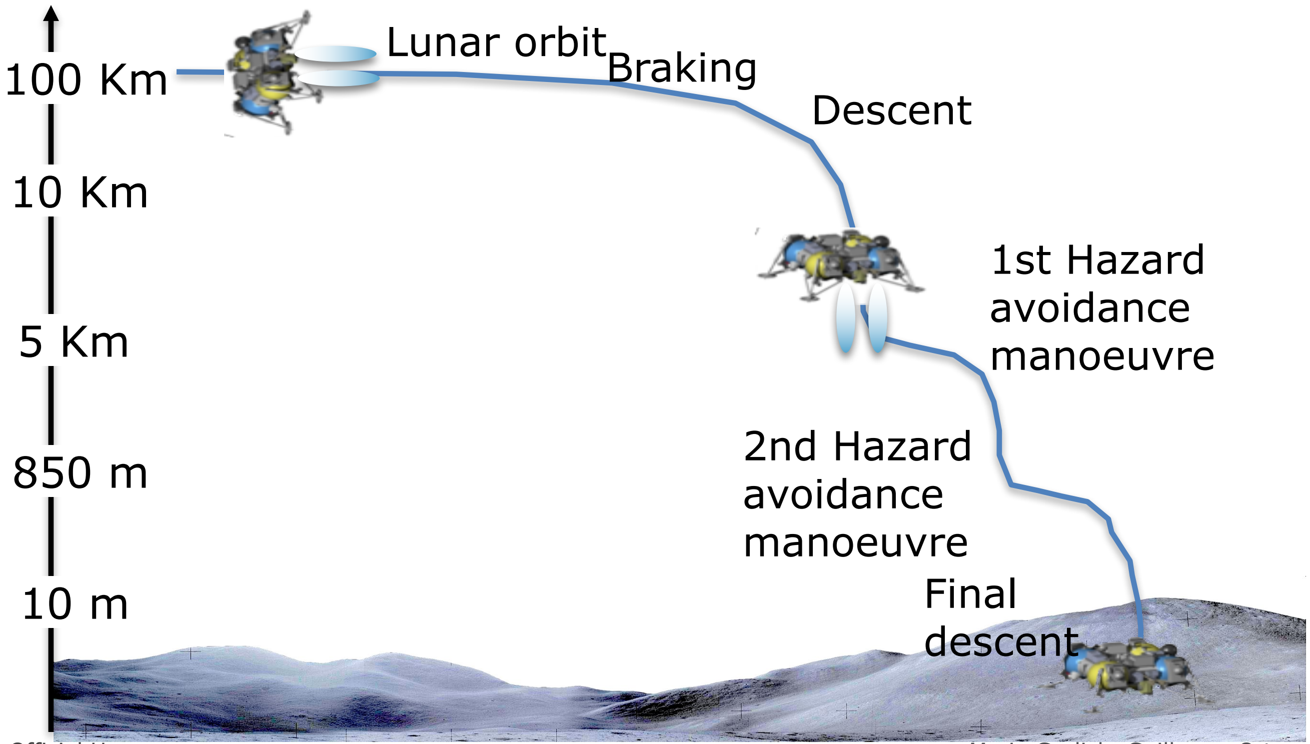
EXAMPLE OF TECHNOLOGY FOR NAVIGATION

Mission Arc	Error Box Requirements (3σ)
Interplanetary cruise	500/10000 km (Asteroid / Planet Encounter) 500-1000 km for low-thrust DS maneuver
Interplanetary approach	3 km up to encounter (asteroid) 30 km up to – 3 hrs (gravity assist)
Far rendezvous	100 km distance error knowledge 1 deg accuracy azimuth and elevation
Intermediate rendezvous	10 km distance error knowledge 0.1 deg accuracy azimuth and elevation
Close cooperative rendezvous	10 m distance error knowledge 0.01 deg accuracy azimuth and elevation
Descent	Velocity < Mach 2 (parachute opening) TAEM gate better than 2000 m wide
Landing and touch down	Velocity < 1 m/s (soft Landing) Precision landing better than 200 m

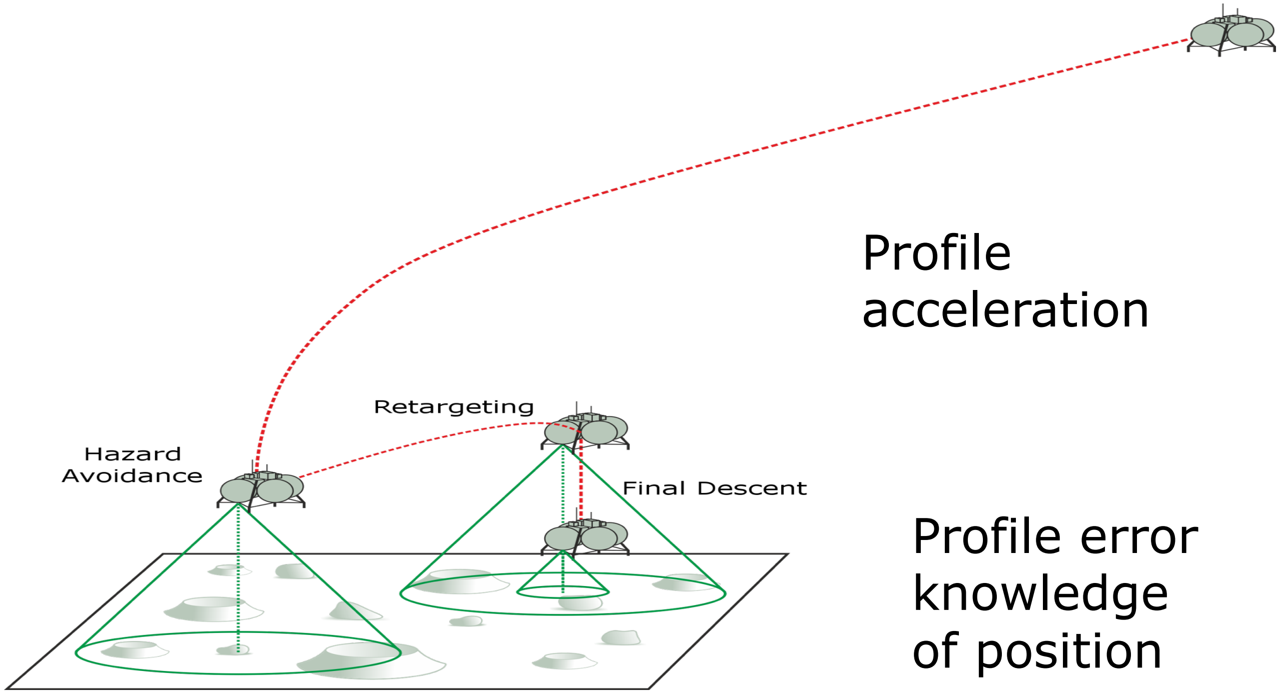
CURRENT NAVIGATION TECHNOLOGY

Mission Arc	Current performances	Means
Interplanetary cruise	10000 km (Asteroid / Planet Encounter) with NPAL camera	
Interplanetary approach	30 km (gravity assist) with NPAL camera	
Far rendezvous	300 m distance error knowledge at 20 Km with LABEN ATV GPS receiver (corporative rendezvous)	
Intermediate rendezvous	1 m distance error knowledge at 1000 m with JENA Laser Range Finder (corporative rendezvous)	
Close cooperative rendezvous	0.2 m distance error knowledge at 50 m 0.01 deg accuracy azimuth and elevation with JENA Laser Range Finder (corporative rendezvous)	
Descent	Velocity < Mach 2 (parachute opening) TAEM gate better than 2000 m wide	
Landing and touch down	Velocity < 5 m/s (hard Landing) Precision landing of 50 Km with ExoMars RDA sensor	

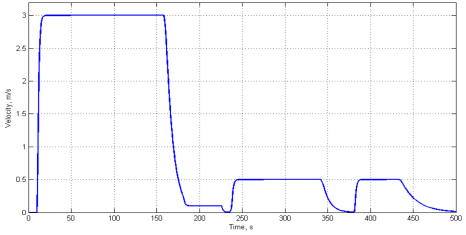
HAZARD AVOIDANCE MANOEUVRES



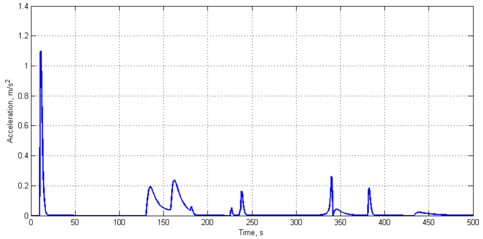
RETARGETING FUNCTION FOR HAZARD AVOIDANCE



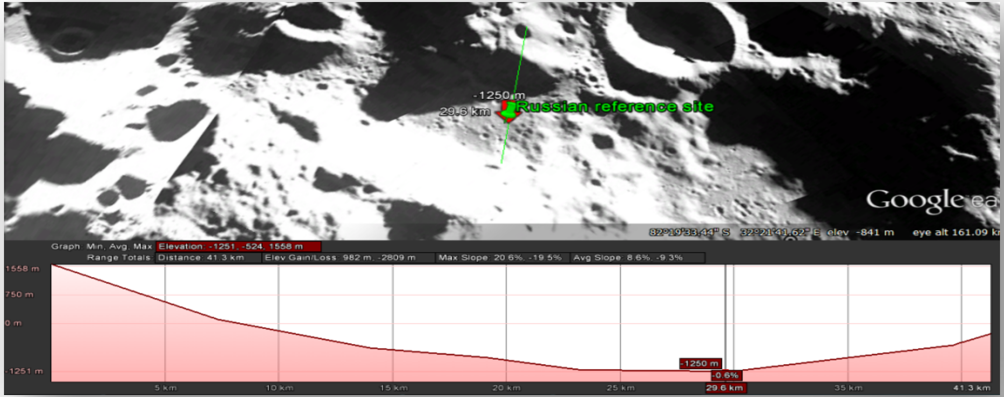
Profile acceleration



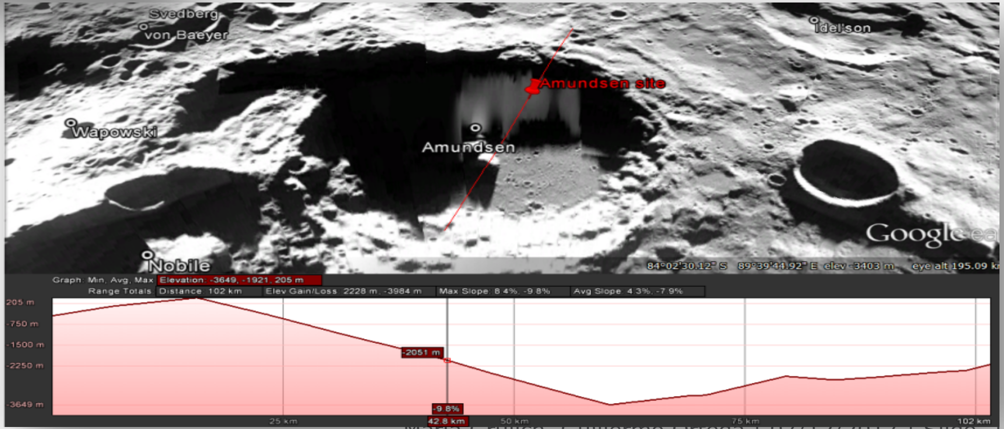
Profile error knowledge of position



MOON LANDING SITES EXAMPLES



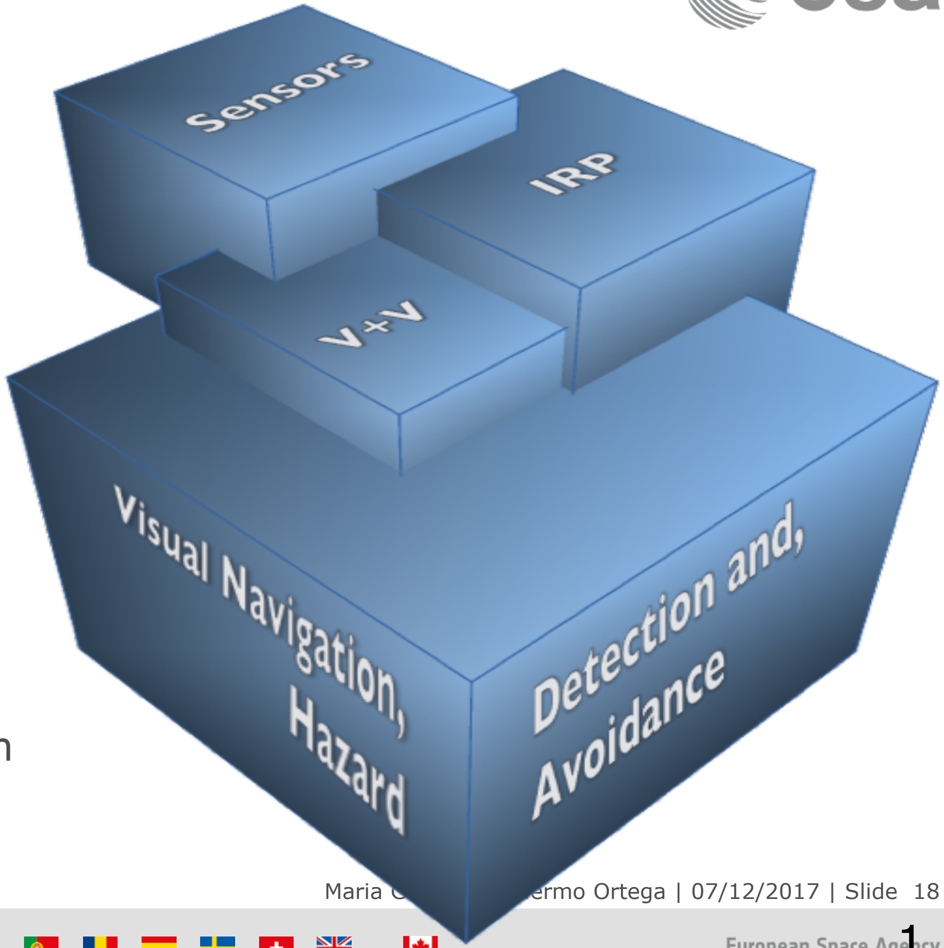
Amundsen site



Shackleton landing site

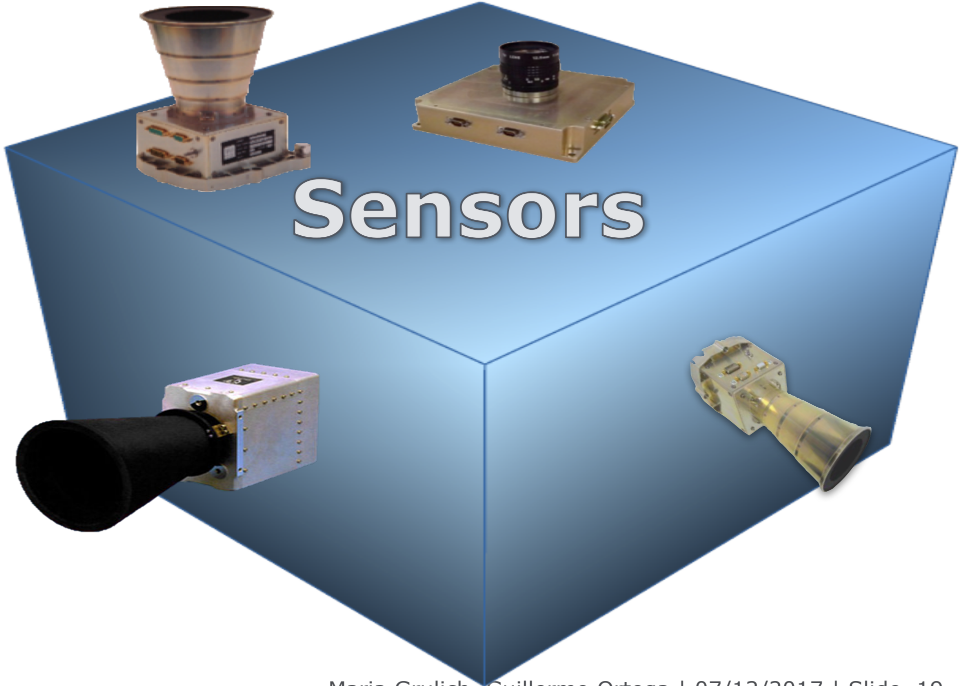
VISUAL NAVIGATION, HAZARD DETECTION AND AVOIDANCE

- Visual navigation, hazard detection and avoidance Building Block composed of sub-blocks:
  - 1.- Sensors
  - 2.- Image Recognition and Processing for Navigation
  - 3.- Data fusion
  - 4.- Advanced Guidance and Control algorithms
  - 5.- High Performance Computing
  - 6.- Multi-disciplinary Optimization
  - 7.- Verification and Validation



SENSORS

- Vision-based cameras
- LIDAR
  - flash, scan
- Multi-spectral cameras
  - IR and UV
- Altimeters
  - laser, radar

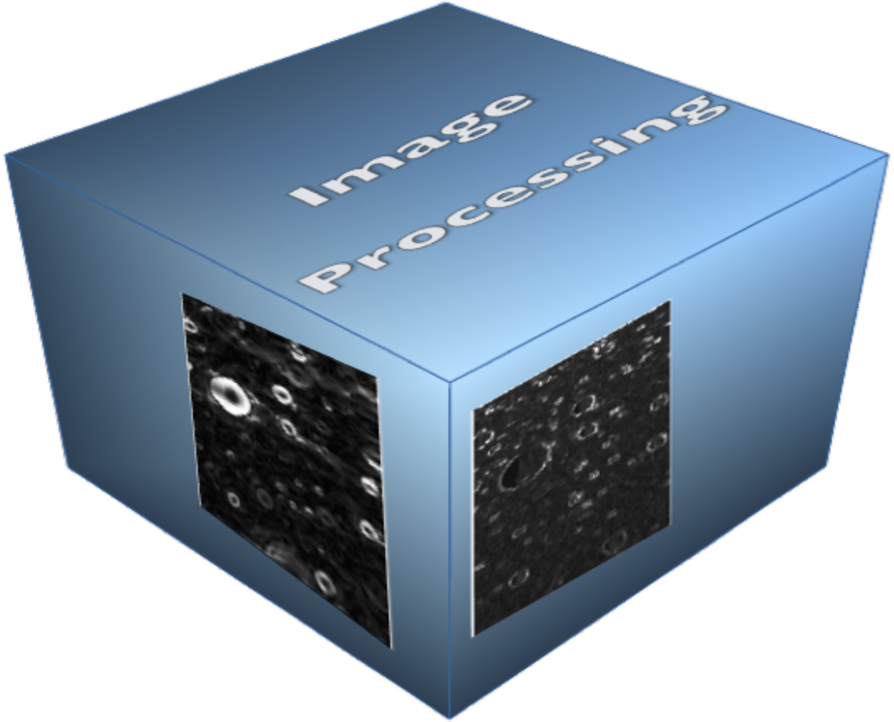


SENSOR EXAMPLES

- NPAL Navigation for Planetary Approach and Landing camera + image processing board + navigation filter
- PILOT navigation camera (more of this in the next presentation)
- ABPA radar and laser altimeters
- JOP scanning LIDAR
- CAMIR InfraRed camera
- ERB HyperSpectral camera

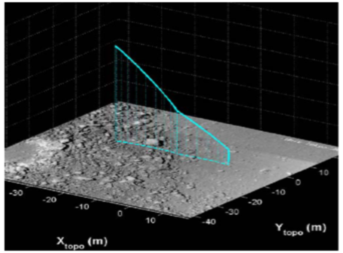
IMAGE RECOGNITION AND PROCESSING FOR NAVIGATION

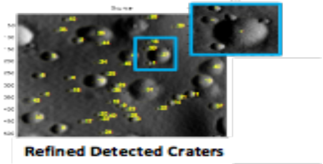
- European FEIC (Feature Extraction and Image Correlation)
- Optical Flow Correlators
- Beyond the Kalman Filter estimators
    - deterministic, stochastic

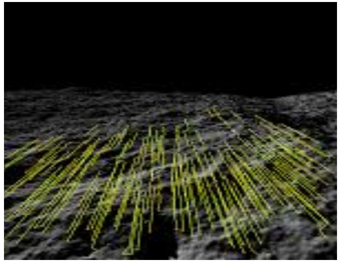


EXAMPLES OF MAGE RECOGNITION AND PROCESSING FOR NAVIGATION

- **Relative Navigation** vs **Absolute Navigation**
- UNI Dundee,UK FEIC (Feature Extraction and Image Correlation): feature detection and feature extraction
- UNI Dresden,Germany Optical Flow Correlator
- GMV Beyond the Kalman Filter estimators:
  - Deterministic estimation: Kalman-like estimation, Wiener estimator (WE), Particle filter estimators (PF), Method of moments (MoM), Minimum-variance unbiased estimator (MVUE)
  - **Stochastic estimation**: Maximum likelihood estimators (ML), Bayes estimator (BE), Minimum mean squared error estimator (MMSE), Maximum a posteriori estimation (MPE), Markov chain Monte Carlo (MCMC

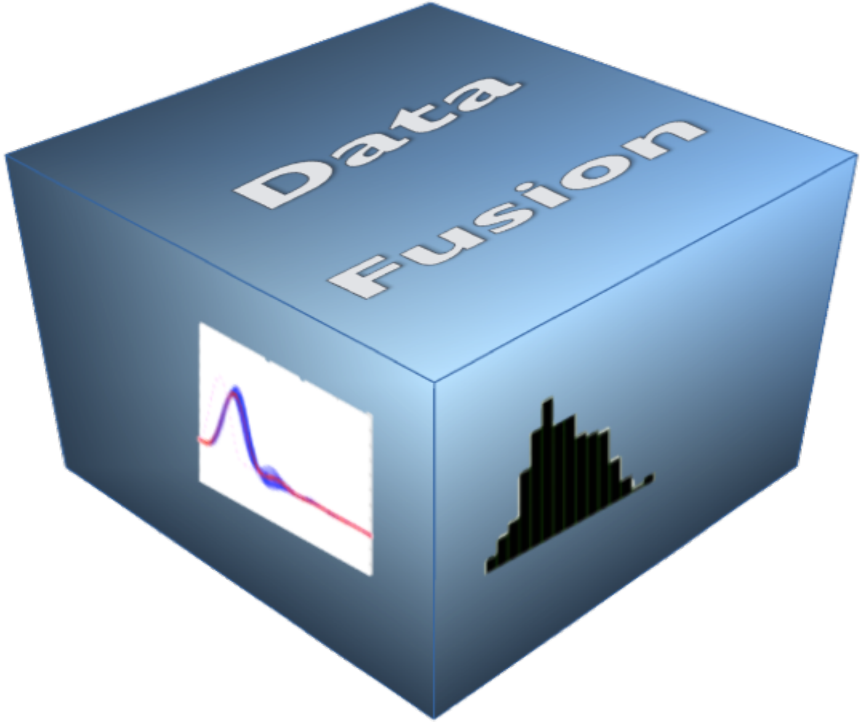






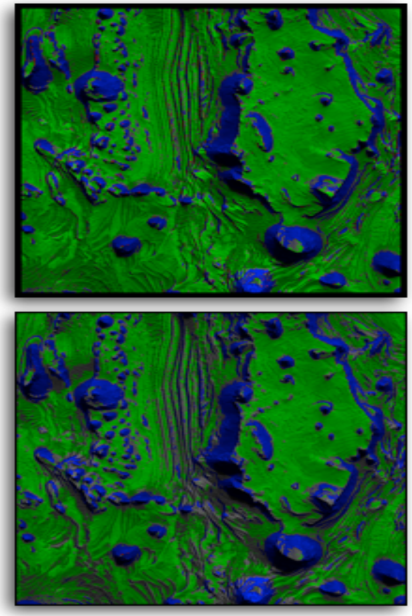
DATA FUSION

- Hybrid Navigators:
  - Loosely coupled
    - STR and INS
    - INS and CAM
    - INS and LIDAR
    - LIDAR and CAM
  - Tightly coupled
    - GPS and INS when GPS is available



EXAMPLES OF DATA FUSION FOR LANDING

- Use of Several sensors to obtain the best possible state vector
- Modular Vision-Based Navigation System design composed of building blocks
  - **Image Acquisition System**: optics, detector, acquisition, pre-processing
  - **Image Processing Board** (IPB): implements both HW and SW IP functions through mix of DSP and FPGA (ASIC in a flight implementation)
  - **Inertial Measurement Unit** (mission-dependent): required by navigation for rolling shutter compensation and aiding
  - **Star tracker**

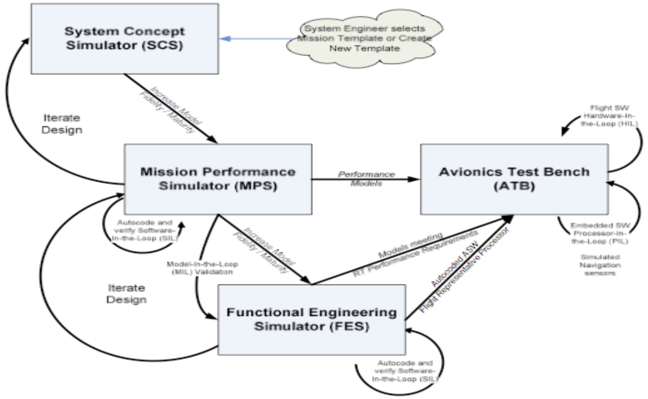


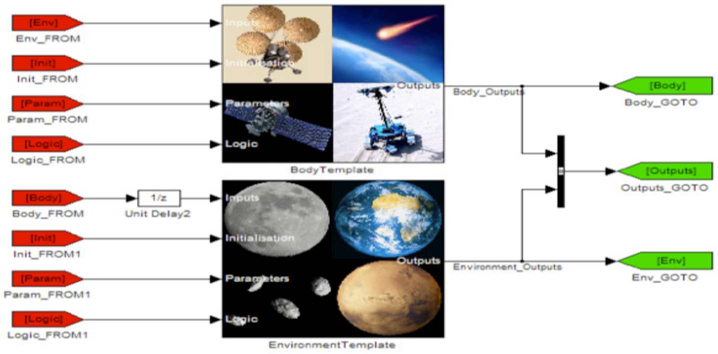
ADVANCED GUIDANCE AND CONTROL ALGORITHMS

- Optimal guidance profiles for descent and landing
- Re-targeting functions
- On-Board Real-Time Trajectory Optimization
- Advanced Robust Multi-variable Control

EXAMPLES OF ADVANCED GUIDANCE AND CONTROL ALGORITHMS

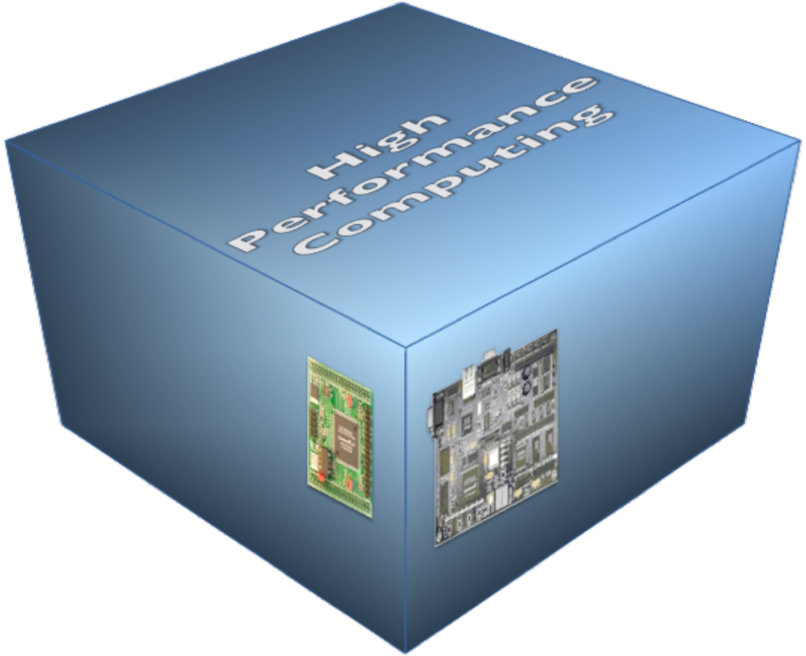
- Optimal **guidance** for descent and **landing**
- Advanced multivariable **robust control** for high accuracy re-targeting functions
- **Automatic generation** of production code (C code) is TargetLink® from dSPACE
- Simulates and analyses Entry, Descent and Landing systems on planetary bodies with or without atmosphere





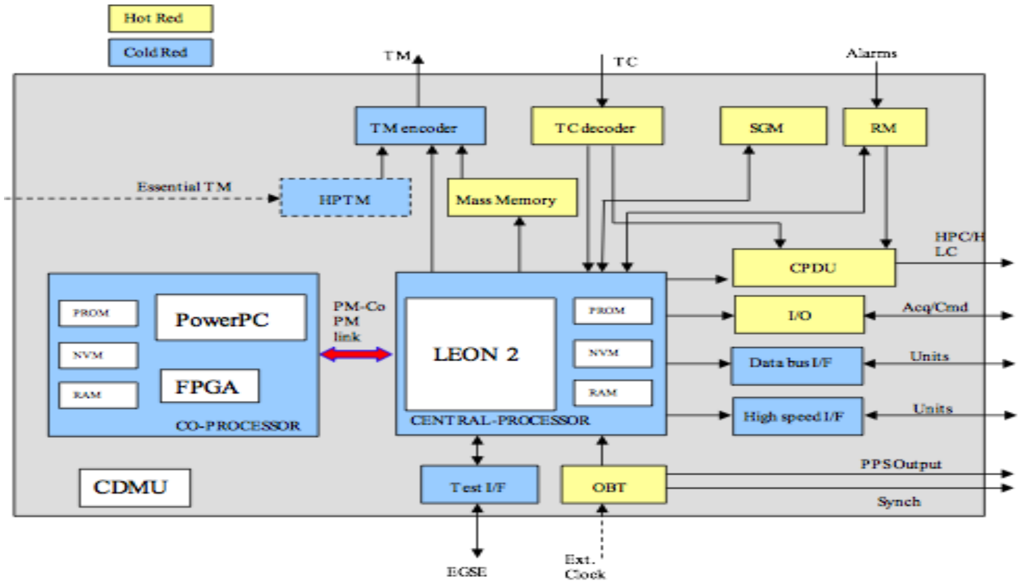
HIGH PERFORMANCE COMPUTING

- Multiple Cores CPUs
- European FPGA and DSP
- High performance data buses
- Electronic Data Sheets
- Many-cores Real-Time Operating Systems
- Time and Space Partitioning



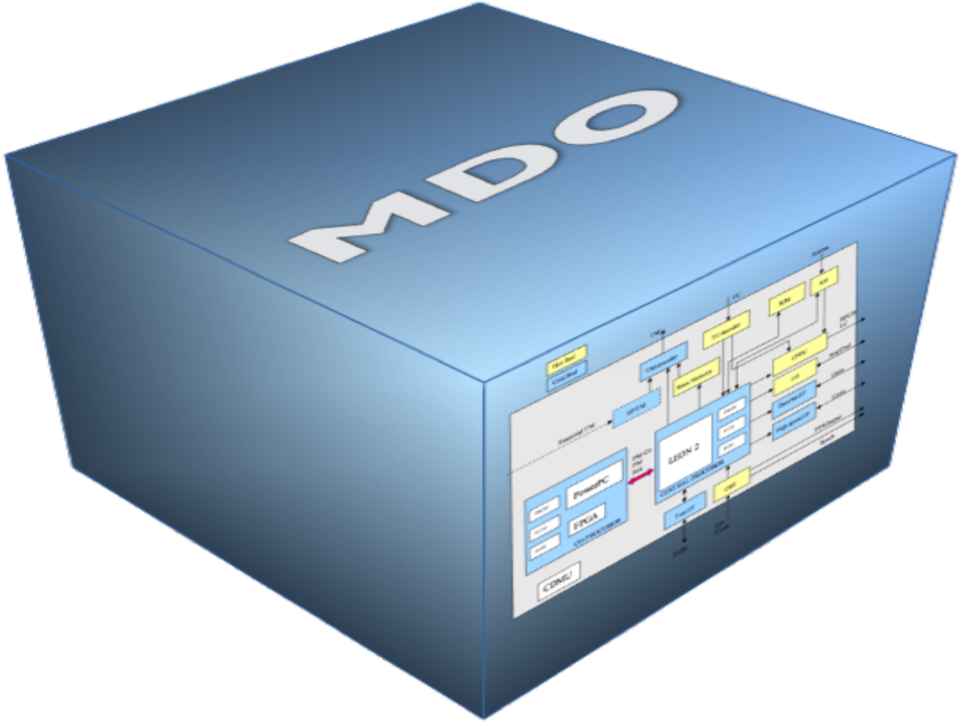
EXAMPLES OF HIGH PERFORMANCE COMPUTING

- European elements for high performing data handling architectures:
  - FPGA and DSP
  - Multi-core computers with fault tolerance features
- Real-time Software performance for high computing architectures



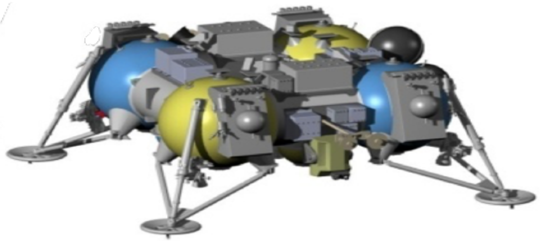
MULTI-DISCIPLINARY OPTIMIZATION

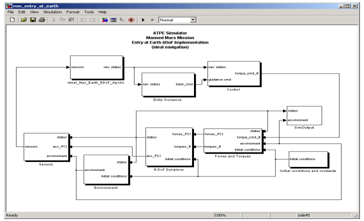
- Optimization of trajectories, propulsion, and staging all at once
- Optimization of placement of sensors and actuators
- Co-design of Structures and Control

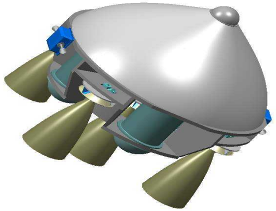


EXAMPLES OF MULTI-DISCIPLINARY OPTIMIZATION

- Optimization at once of trajectories, structures, propulsion for Moon landers
- MDO for Moon ascent vehicles: single stage vehicle with all-at-once design optimization
- Co-design of control and structures
- Optimization of sensor placements across mission arcs, mission types, and mission requirements

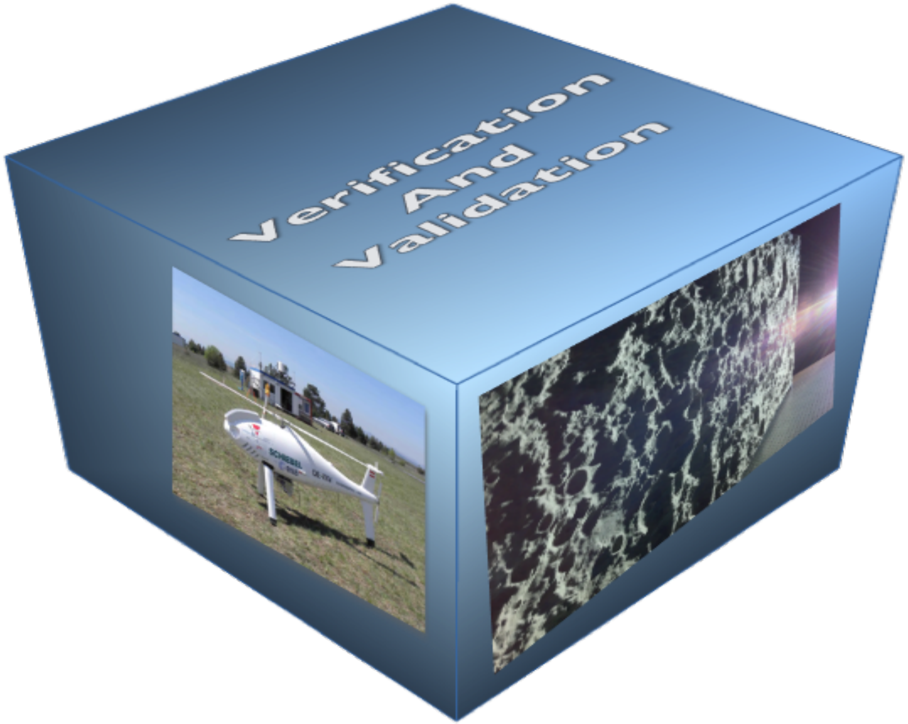






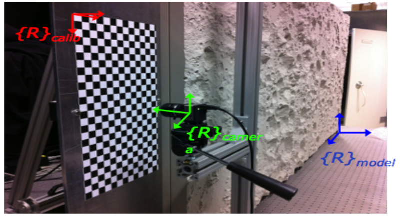
VERIFICATION AND VALIDATION

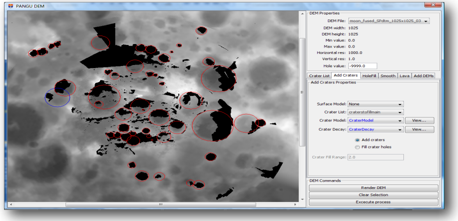
- Simulators and Emulators
- SIL=>PIL=>HIL testing sequences
- Ground test benches for optical, infrared and LIDAR V+V
- All-at-once verification and validation facilities
- In-Orbit Demonstrators

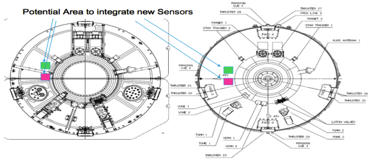


EXAMPLES OF VERIFICATION AND VALIDATION

- PANGU **Surface modeller**: realistic surfaces (MLI, OSR, solar cells…)
- GNC **Ground Testing Facilities**
  - DLR TRON For Descent and Landing
  - DLR EPOS For Rendezvous and Docking
- PLGTF (ESA) Ground demonstrator
- MORPHEUS (NASA) Ground demonstrator
- SPARTAN Ground Demonstrator
- LIRIS In-Orbit Demonstration opportunities







Ready to Start Exploring?

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