**GMV**

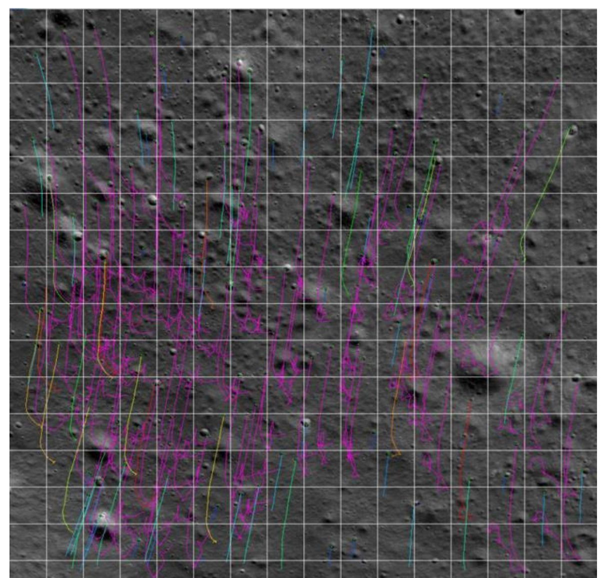
# Avionics Systems for the Exploration of Asteroids and small moons

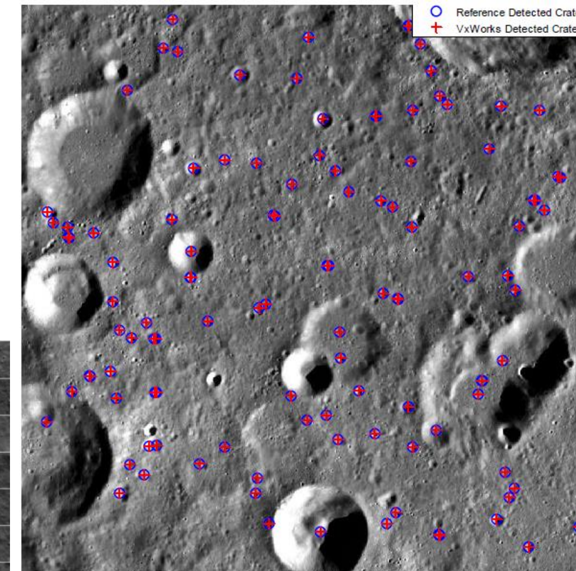
# CONTENTS

- Vision Based Technology for improving Navigation accuracy
- AIM case
- PILOT-B case
- MREP-VBNC-PHOOT case
- Using HW in the loop test-benches (lesson learned)

# Vision Based Technology for Improving Navigation Accuracy

- Two types of Vision Based Navigation can be used in order to improve the Navigation Accuracy.
- Absolute Navigation uses the knowledge of specific knowledge of reference points (Landmarks) to be detected and recognized in the images in order to improve Navigation Solution
- Relative Navigation uses image characteristics (Features) to be uniquely detected in sequences of images in order to improve Navigation Solution
- In order to use these technologies on-board, development and validation steps have to be performed.
- The HW for using these technologies has to be carefully dimensioned



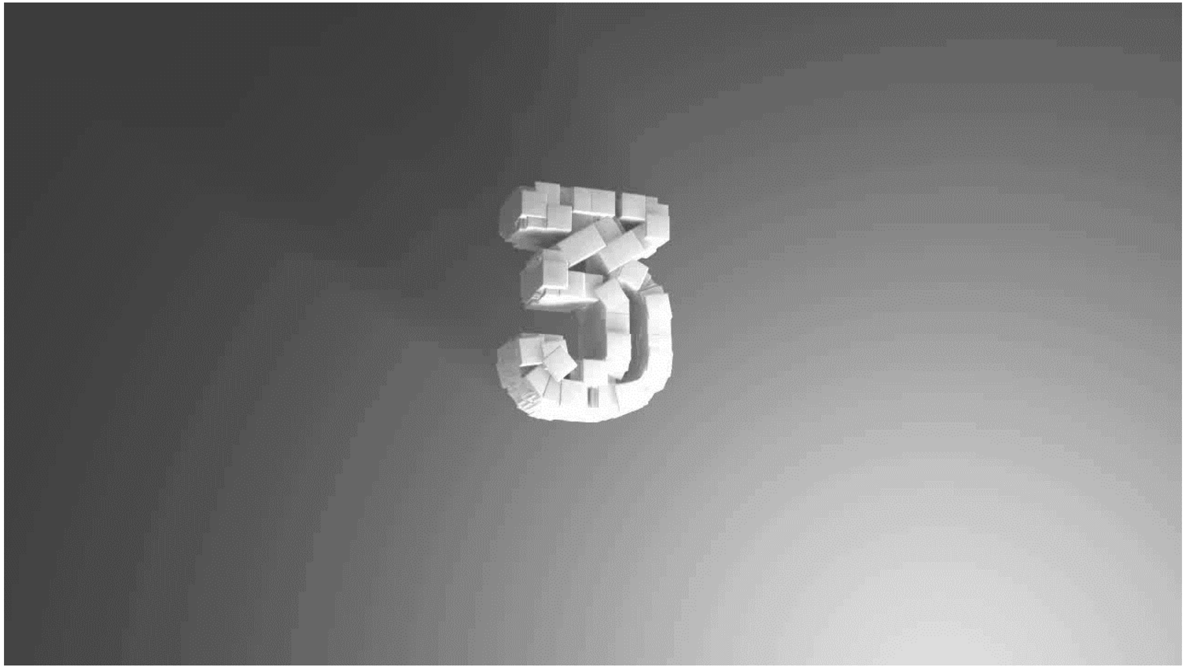


# TOWARD SMALL MOONS

- Asteroids Impact Mission (AIM) is the European contribution to the NASA AIDA mission
- AIM is intended to qualify two way optical communications for deep space (TBC), carry at least three smaller spacecraft (1 Lander and 2 cubesats) and map the smaller moon Didymoon with thermal infrared imager and high and low frequency radar performing science on a binary asteroids system.
- ESA considers AIM to be a small mission opportunity to demonstrate technologies. High technology re-use from past and current missions under design is foreseen
- One of the technology to be demonstrated is the use of Relative Vision based Navigation

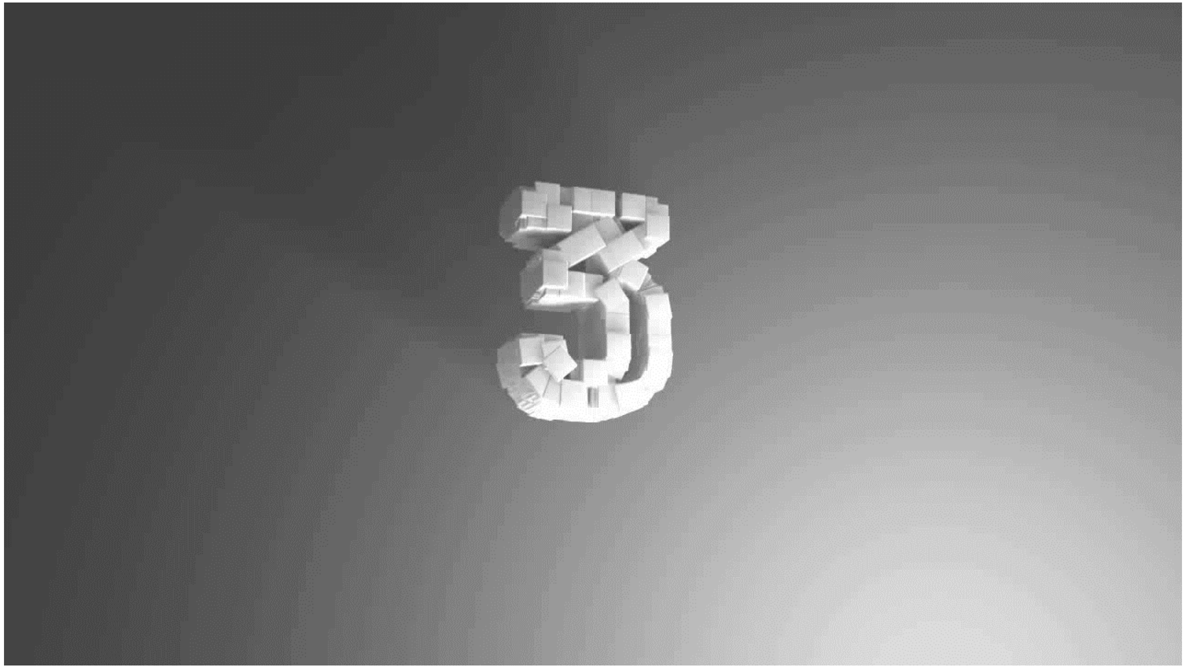
# TOWARD SMALL MOONS

- Relative Navigation is planned to be used in the spacecraft in order to improve the Navigation accuracy before the separation and ensure the correct landing of Mascot II
- GMV is investigating the use of this technique using different cameras and architectures
- NPAL camera has been used in Platform-art Robotic Facility in order to perform an initial validation of the technology
- The Flight Spare Model of Dawn Framing Camera developed by Max Planck Institute has been used in Static test bench



# TOWARD SMALL MOONS

- Rendering SW is used to perform closed loop simulation in order to validate the Navigation
- The Flight Spare Model of Dawn Framing Camera developed by Max Planck Institute has been used in Static test bench
- The Dawn Framing Camera  will be also used Platform-art Robotic Facility
- The Dawn Framing Camera  can produce images 1 per minute which make quite challenging the tracking of the features



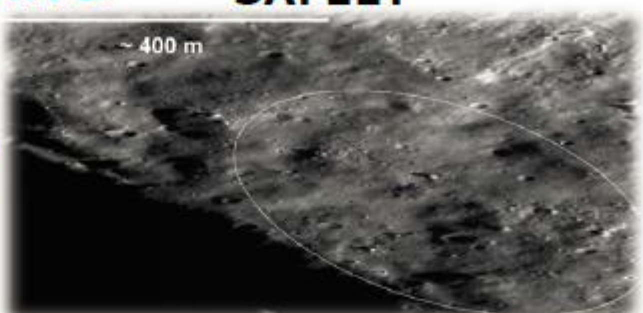
PILOT

# TOWARD PINPOINT LUNAR LANDING

**P**RECISE
**I**NTELLIGENT
**L**ANDING USING
**O**N-BOARD
**T**ECHNOLOGY

**PRECISELY**

**SAFELY**

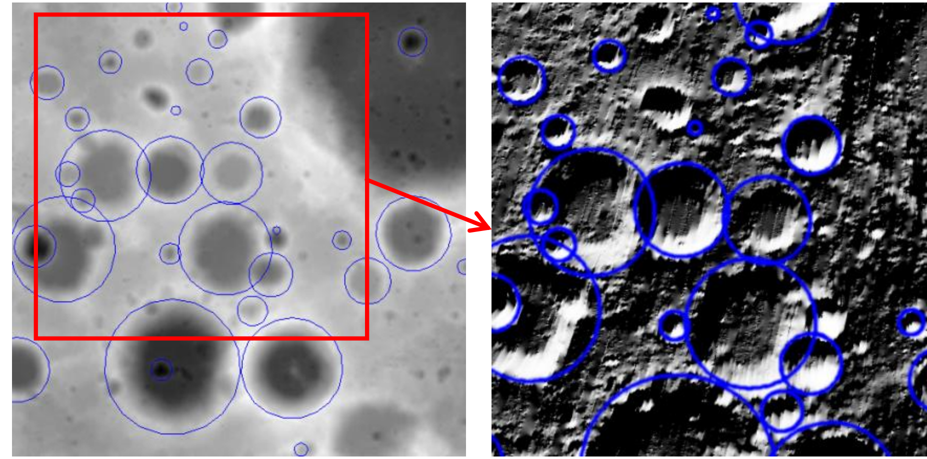



- PILOT is a Navigation System product based on Vision Based Technologies
- PILOT provides accurate Navigation and Hazard Detection and Avoidance in Orbital and Lunar Landing scenarios
- Using PILOT, it will be possible to land safely on the Lunar surface with an accuracy of ~200 meters
- PILOT navigation System is actually in phase B of the development but the Vision Based Technologies have already reached Technology Readiness Level (TRL)-5 in previous activity.
- PILOT is supposed to be mounted in the Russian Luna-Resurs Mission as main navigation function during landing operation

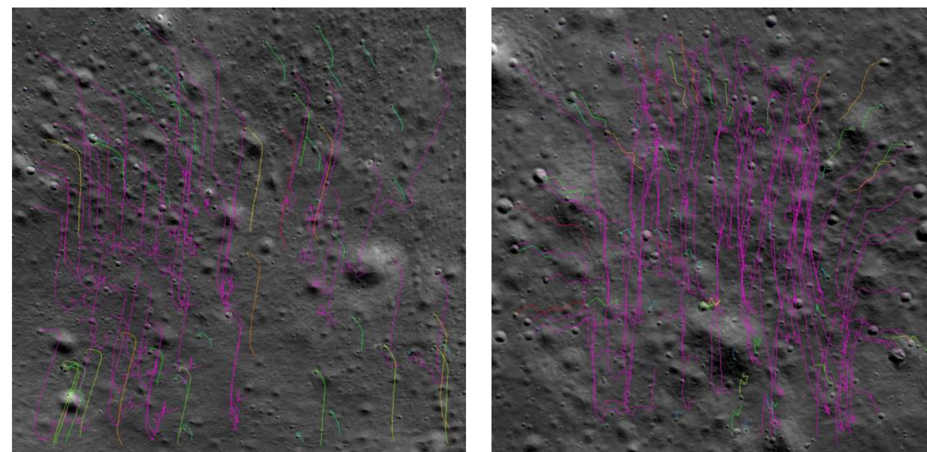
# PILOT-B+

- GMV participates in PILOT developing the 2 cores vision based technologies (RelNav & AbsNav) of the Navigation system
- AbsNav provides precise Position estimation recognizing known craters of the Lunar surface at frequency higher than 0.05 Hz
- RelNav provides precise Velocity estimation tracking unknown features of the Lunar Surface at frequency higher than 2.5 Hz
- Currently, the architecture is under revision by the prime. In previous activity the AbsNav and RelNav components have been tested in Virtex-4 XC4VLX100 and CPCI-CPU/750 FX

AbsNav

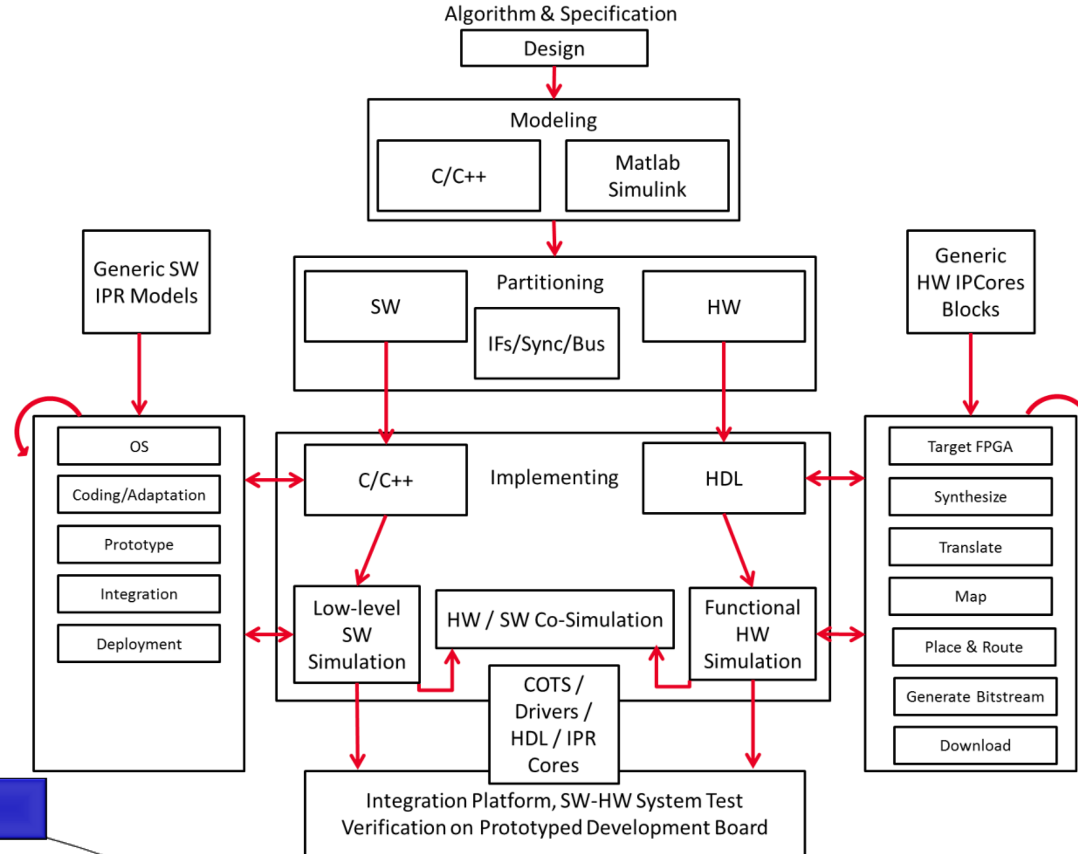


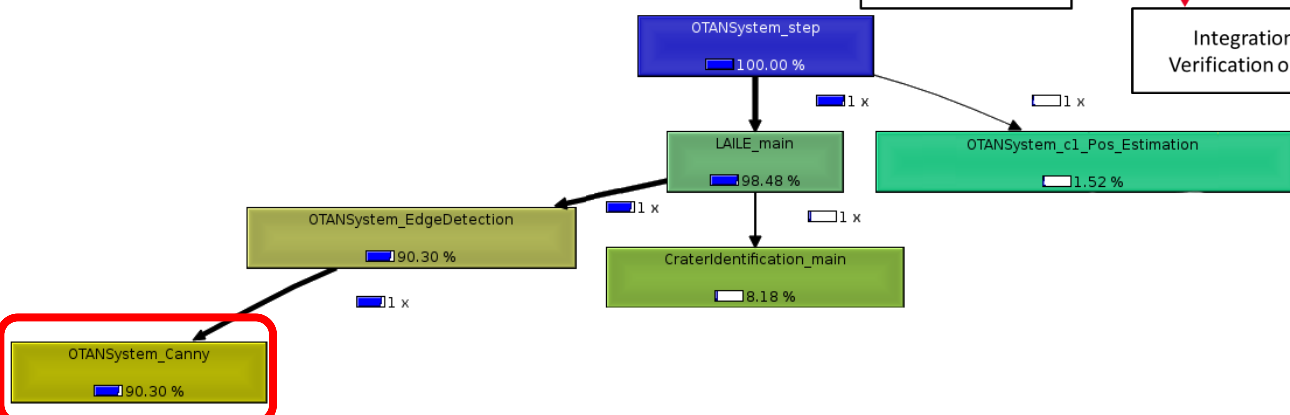
RelNav



# PILOT

- AbsNav and RelNav components follows the HW/SW co-design approach
- The SW is partitioned and detailed profile is performed taking into account the processing time requirements
- The most demanding functions are re-designed in VHDL.
- The other parts of the original SW are maintained as SW components
- The SW components follows the standard development and validation approach

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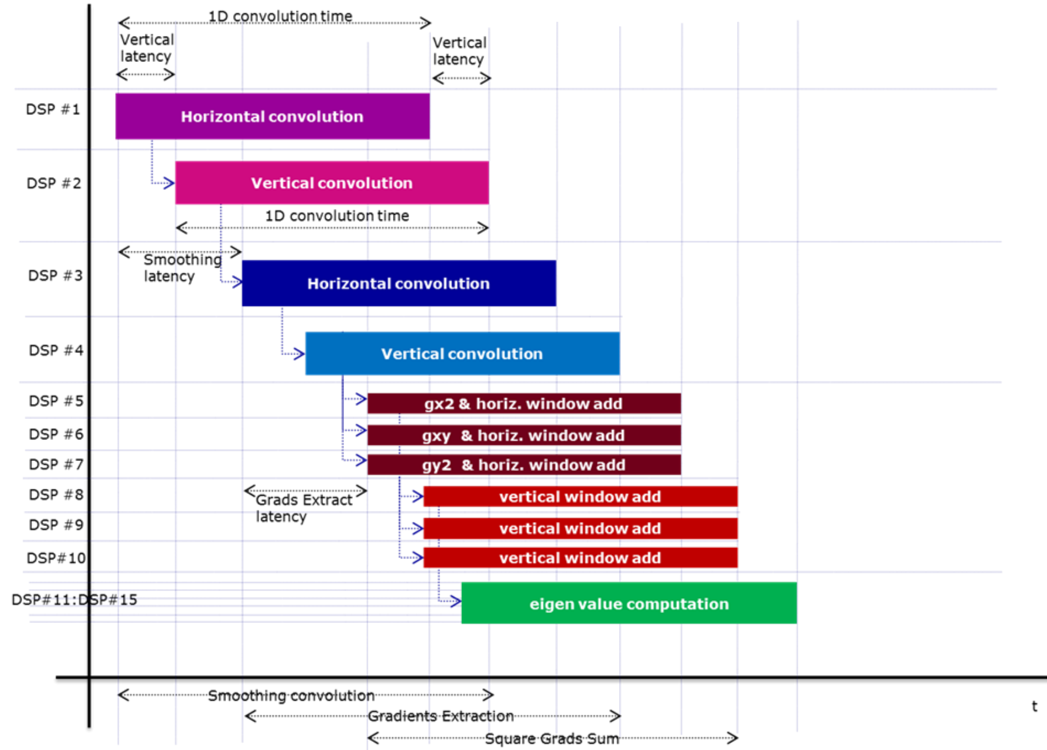
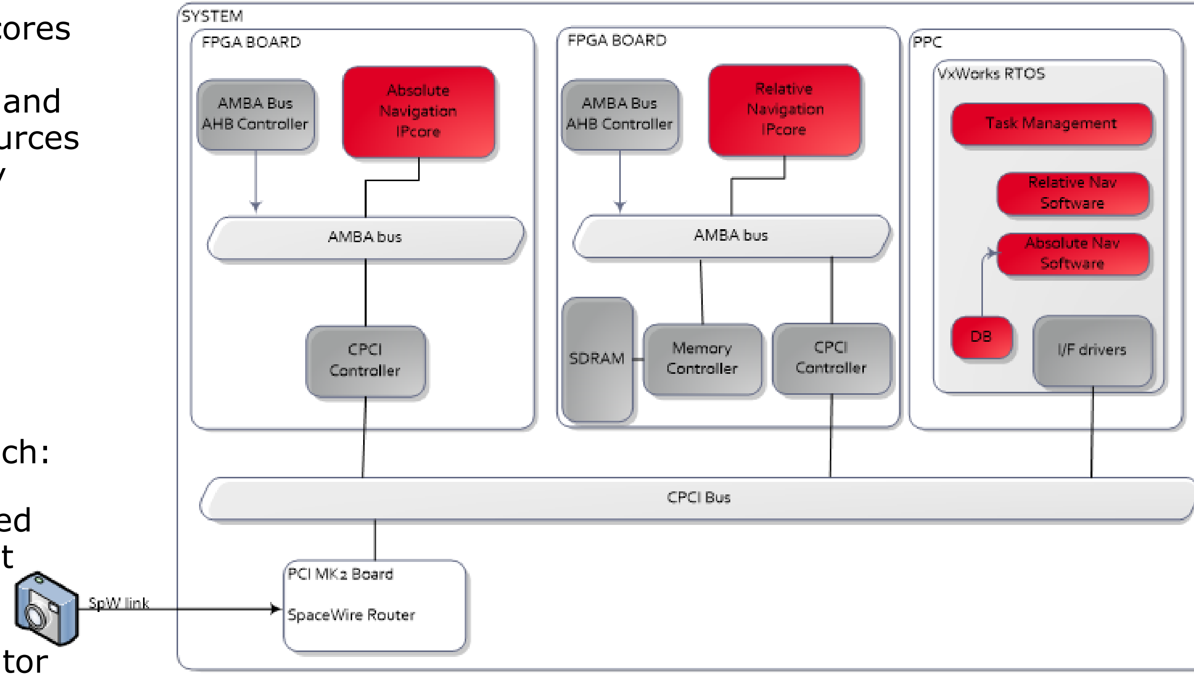
# PILOT

- The function considered in the HW IPcore are re-designed introducing:
- Parallel implementation: e.g. 2D convolutions are transformed in 2x1D convolutions
- Fixed Point Arithmetic: it is introduced observing the dynamic range needed for each data in order to avoid losing accuracy
- Pipelining: The streaming data flow is designed introducing chain of interconnected and synchronized blocks
- MACs (Multiply-accumulate) operations through interconnected DSP slices
- Memory Control: introducing specific FIFO buffers for big amount of memory management



# PILOT

- Communication interfaces IPcores are than introduced and synchronized in order to give and provide access to all the resources (AMBA Bus, cPCI and Memory controllers)




- The Validation follows the incremental validation approach:
- SW unitary tests are performed for each of the SW component
- HW IPcore unitary tests are performed using VHDL simulator utilities
- HW-SW integration tests are performed checking the correct communication between different modules and HW and SW.
- System tests are performed downloading the bitstream of HW IPcore in the FPGA and performing the validation of the entire HW/SW co-design.
- The achieved performance are compared with the initial SW version of the algorithm

# TOWARD PHOBOS

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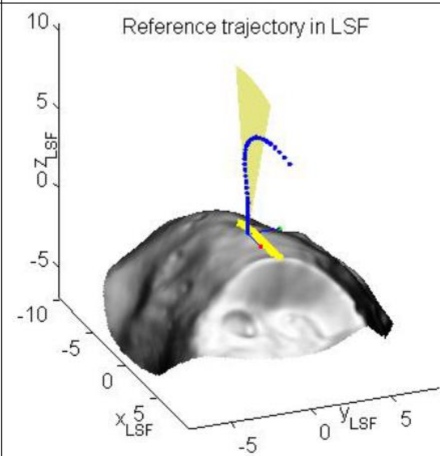
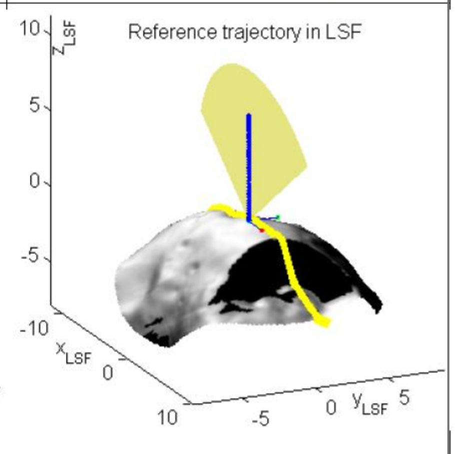
<tr><th></th><th>Direct Descent</th><th>Descent with Hovering</th></tr>
<tr><td>Sun latitude of 5º wrt Phobos Frame<br><br>Landing Site at<br>90º Longitude<br>5º Latitude in Phobos</td><td></td><td></td></tr>
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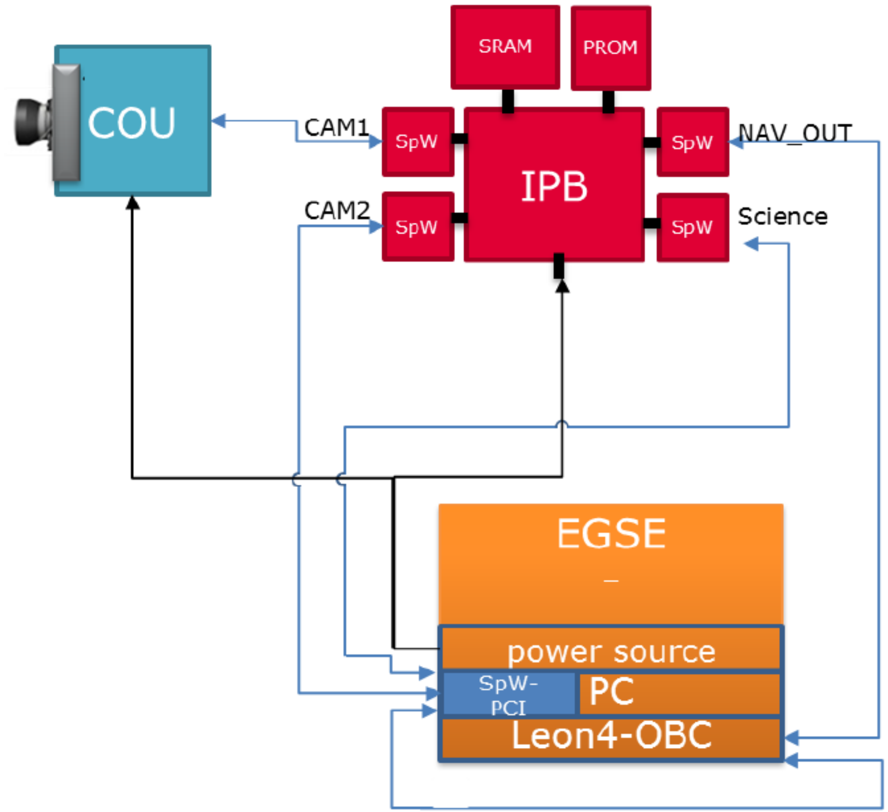
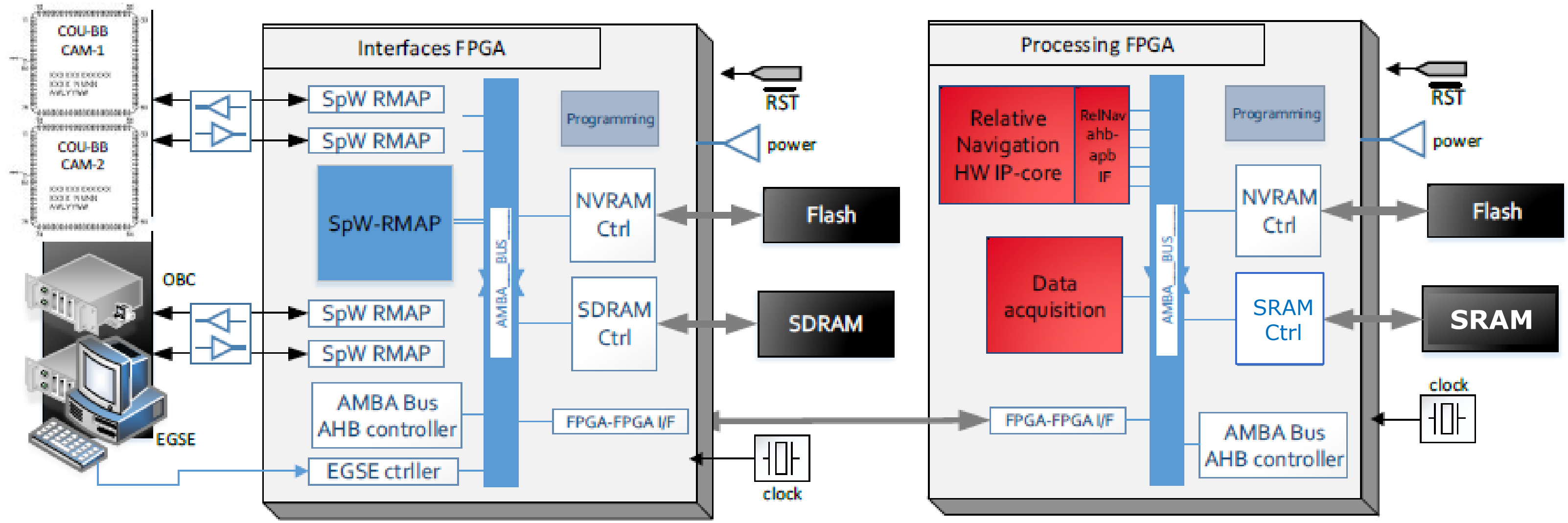
- GMV has been awarded with MREP-VBNC-PHOOT. The objective of the activity is to develop an Engineering Model (EM) of the Vision-Based Navigation Camera (VBNC) for Phobos Sample Return (PhSR) Mission.
- The VBNC is composed of an optical head called Camera Optical Unit (COU) and an Image Processing Board (IPB)
- The main difference between the development performed in PILOT is that the Relative Navigation component is already integrated in the Camera

# MREP-VBNC-PHOOT

- FPGA-VHDL Image Processing implementation in IPB will include Image calibration and Processing of calibrated images to extract navigation data
- IPB-COU SpaceWire link in order to minimize the transfer time of the calibrated images. It includes 2 SpaceWire links, Redundancy and EGSE debugging connection
- IPB-OBC processor SpaceWire connection. It includes 2 SpaceWire links:
- Once the image is processed few data is nominally transmitted to OBC.
- The Imaging mode would transmit the entire images.
- Redundancy, Downlink capabilities and EGSE debugging connection



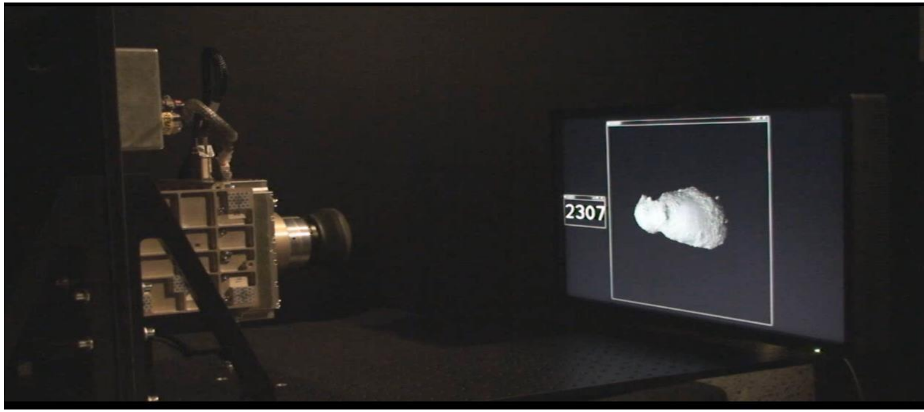
# MREP-VBNC-PHOOT




- The IPB is designed in order to integrate 2 FPGA in the same board. This allows FPGA-FPGA IF
- 1st FPGA is Flash based FPGA dedicated to Interfaces receiving the image from the COU, providing in output the raw image to the EGSE for debugging and storing purposes and receiving TC.
- 2nd FPGA is an High performance SRAM based FPGA dedicated to the Image Processing algorithm. It receives the image and provides the feature tracked

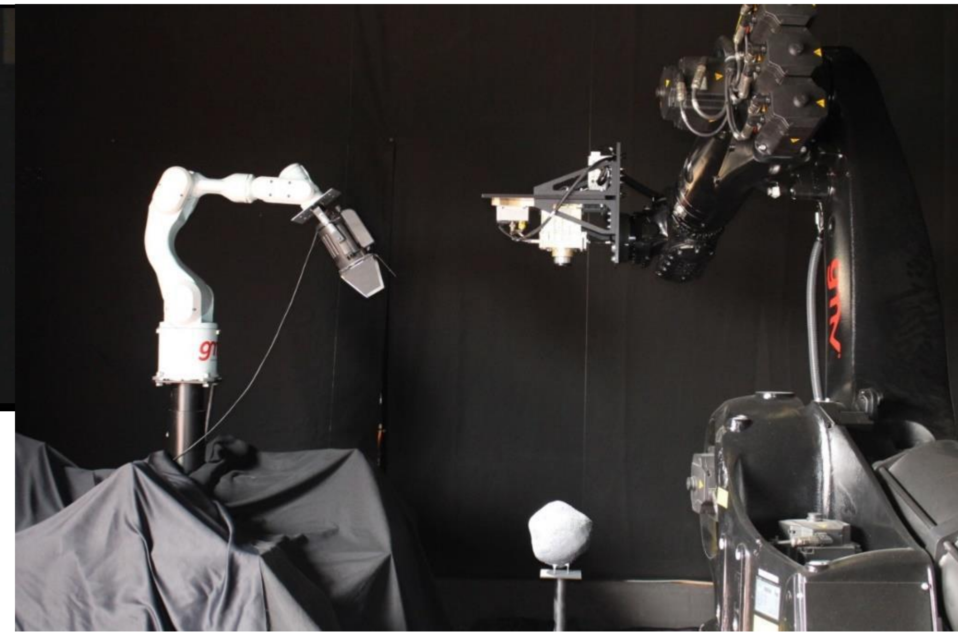
Lesson Learned

# USING HW IN THE LOOP TEST BENCHES




Static Test-bench at GMV for PIL/HIL

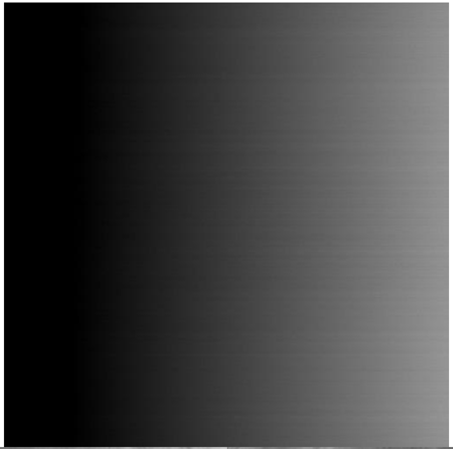
- Using HIL test benches requires a careful design of the scenario that have to be simulates
- Scenario if too large may need to be broken in different part applying different scaling factors and mock-ups with different details

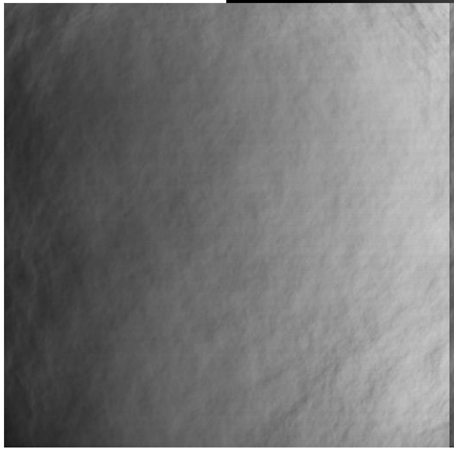


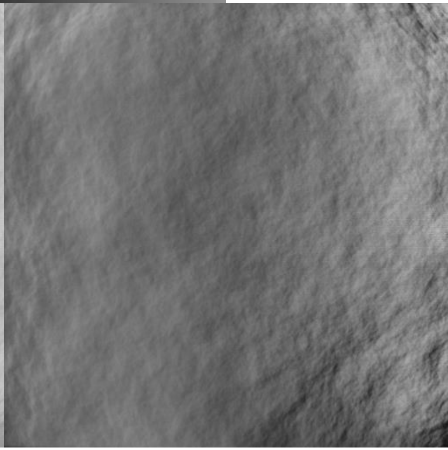
GMV Platform-art Robotic Facility for PIL/HIL

# USING HW IN THE LOOP TEST BENCHES

- The use of cameras designed for space environment may be difficult in laboratory environments
- In the NPAL camera, the optics is designed to focus at infinity. It means that at the distance used in the testbench the image is completely out of focus. The problem can be solved using fixing collimators or opto-tune lens, but limitation still exists and depends on the simulated scenario.
- In the DAWN camera, the camera is designed to work at -50º. Using the camera at ambient temperature the camera presents impressive dark current effect. The problem is solved calibrating the image taking into account the dark current. The calibration may results in a small loss of dynamic range in part of the image. Also the DAWN camera is designed to focus at infinity, so use of collimators or opto-tune lens is required to acquire images in laboratory.







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# THANK YOU