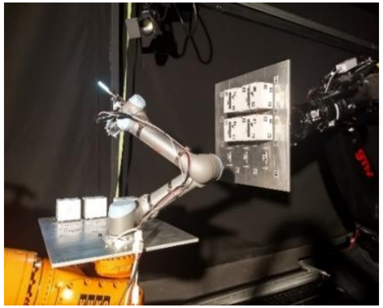
HORIZON 2061 SYNTHESIS WORKSHOP

THE ROLE OF ON-BOARD AUTONOMY IN FUTURE SPACE EXPLORATION: ERGO'S AUTONOMOUS LONG TRAVERSE ACHIEVEMENTS IN MOROCCO DESERT

European Commission



HORIZON 2020

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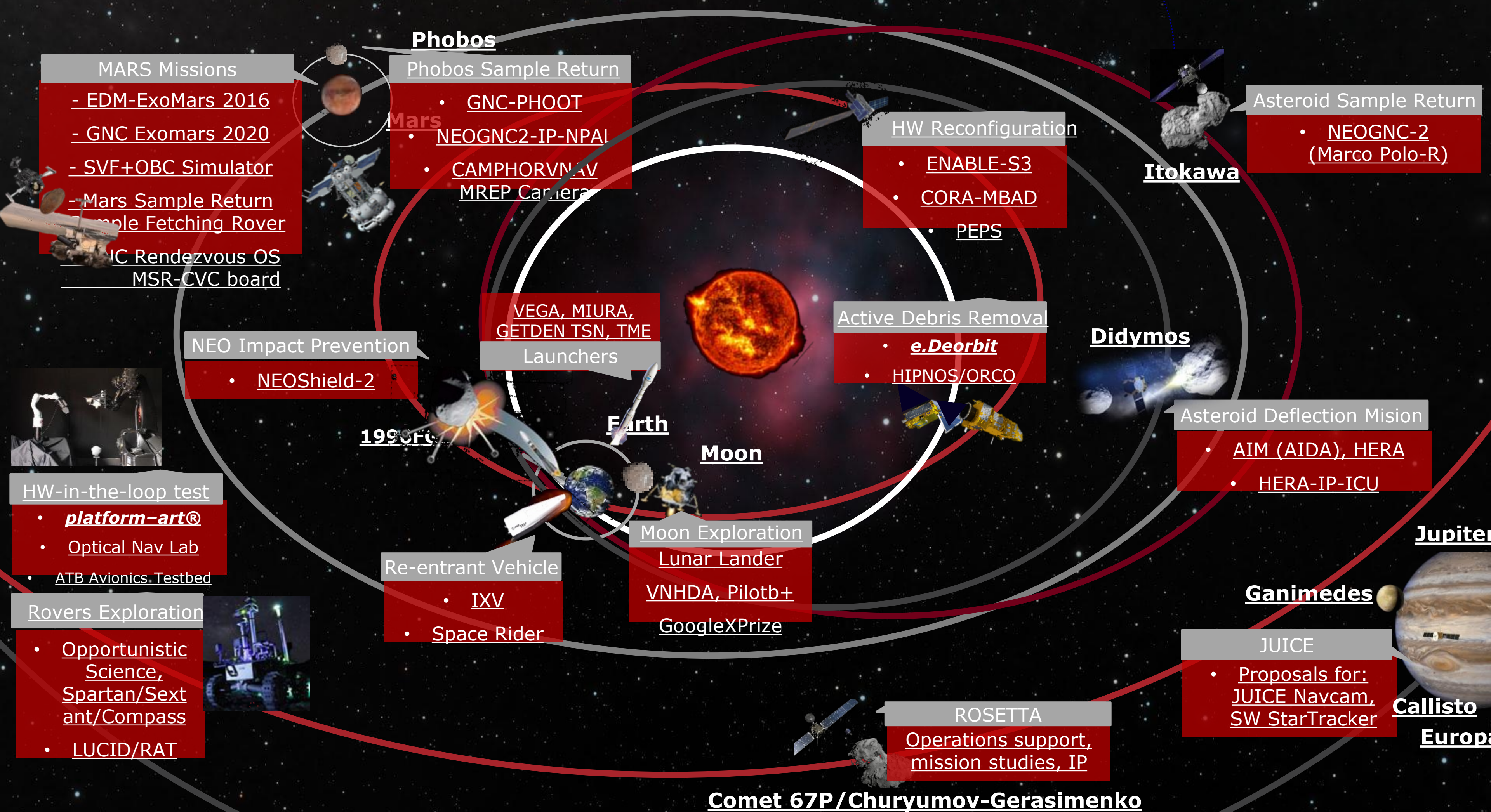

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GMV technology & staff have supported a total of

294

space missions

WHAT IS ON-BOARD AUTONOMY?

- The term “autonomy” refers to the capability of a system to work without human intervention.
- There are multiple capabilities for a robot associated to autonomy, such as:
  - **High-level goal commanding:** capability of a robot to be commanded via high-level goals (f.i. “go to point (x,y) and take an image”, “pick sample at (y,z) and take it to (w,p))”.
  - **Autonomous Guidance**: capability to traverse autonomously a terrain in a safe way, reaching different objectives, and avoiding obstacles
  - **Mobility planning (for robotic arms):** Capability of a robotic arm to perform complex operation (pick an object, drop an object, move) in a safe manner (avoiding collisions with the robot or the environment)
  - **Serendipitous science:** capability to detect autonomously interesting events (f.i. rocks with specific characteristics) and change the current plans in order to gather science (f.i. take pictures of them at a closer position), without abandoning other high level goals (that are postponed for later)

All these capabilities have been developed and tested within ERGO

WHY ON-BOARD AUTONOMY?

On-board autonomy allows to:

- Maximize science return
- Overcome communications delays
- Reduce operational costs
- Increase mission reliability
- Make feasible complex mission scenarios
- Optimization of on-board resources utilization
- Robustness/fast reaction with respect unexpected events
- Optimize planetary surface exploration
- Support to future human exploration

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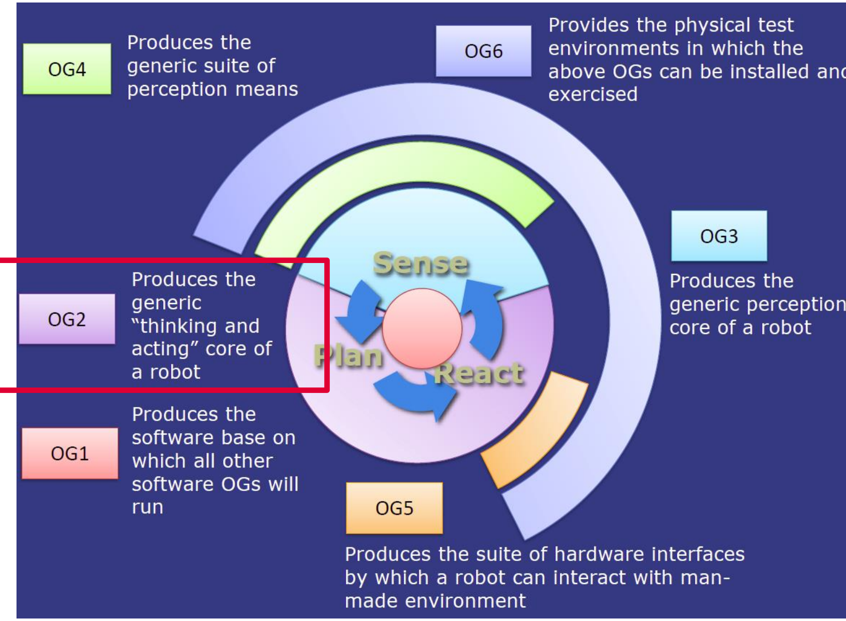
ERGO IN PERASPERA 2016

- **ERGO: EUROPEAN ROBOTIC GOAL-ORIENTED AUTONOMOUS CONTROLLER (http://www.h2020-ergo.eu/)**
- **ERGO is the second of the PERASPERA 2016 Operational Grant (OG) Building Blocks**
- **ERGO-OG2 focuses on design and development of On-Board Autonomy framework**
  - Two years project (ended in Feb 2019)
  - Outcome of all OGs designed to be compatible (common IRD)
  - Each OG tested its SW products into orbital and surface infrastructures/test environments provided by OG6
  - Each OG provides a set of components & tools & doc for its use
  - ERGO has just finished and its results are available for future EC or ESA projects



- Constitutes building blocks to be used in subsequent PERASPERA projects
- Two scenarios:
  - Orbital
  - Planetary

ERGO TOOLS AND COMPONENTS

SW1: Core framework

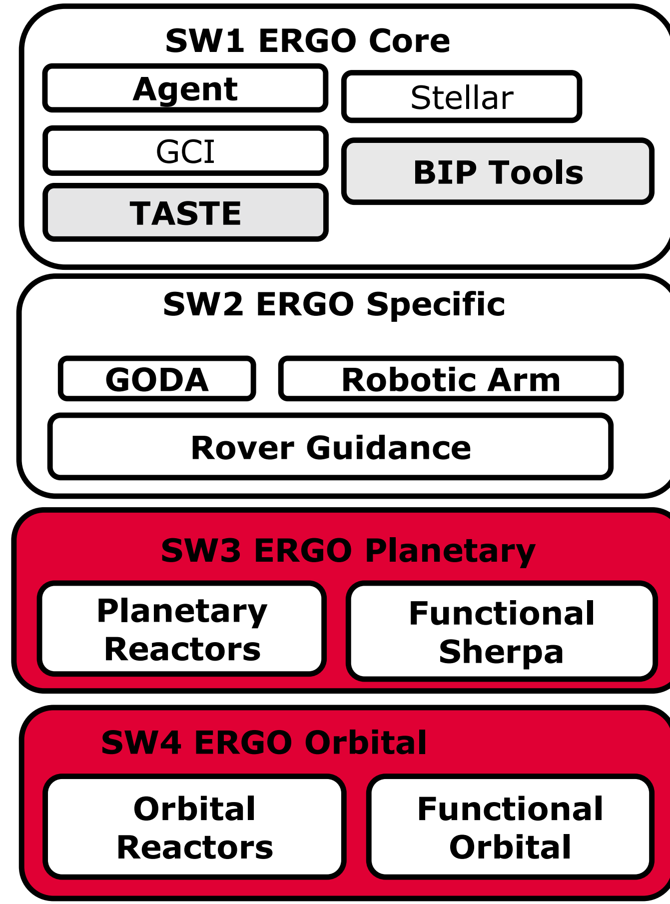
- TASTE extensions
- On-board Agent
- On-board planner: Stellar
- Ground control interface
- BIP (FDIR) tools

SW2: Mission-specific components

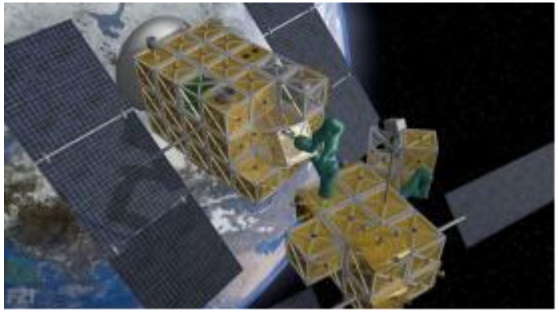
- Guidance
- Robotic arm library
- Scientific detector (GODA)

SW3: Application SW (Planetary)

SW4: Application SW (Orbital)



ORBITAL DEMOSTRATOR: IN-ORBIT SERVICING

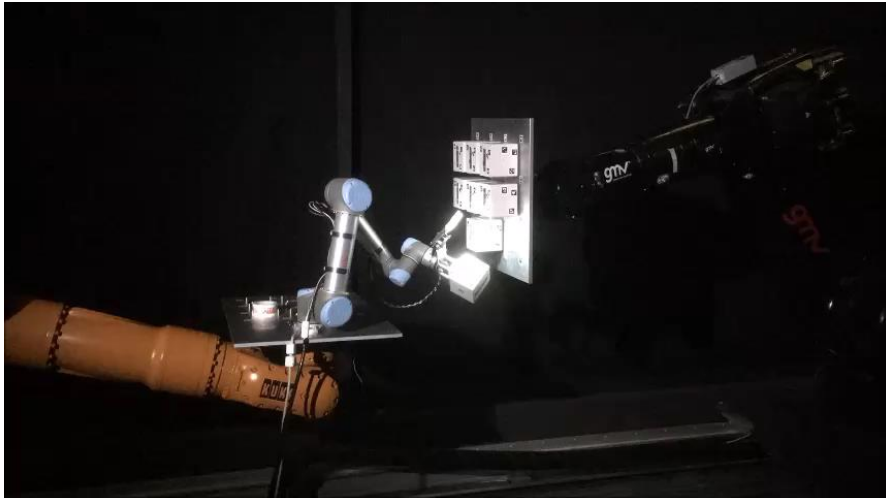


Orbital scenario:

- Autonomous Advanced Payload Modules (APM) replacing by a servicer Spacecraft

Objectives:

- E4 goals commanding: to switch from one configuration to another
- Average planning time: 20s
- Replanning under errors (e.g. faulty APM)
- Lowering autonomy when target deviates from chaser



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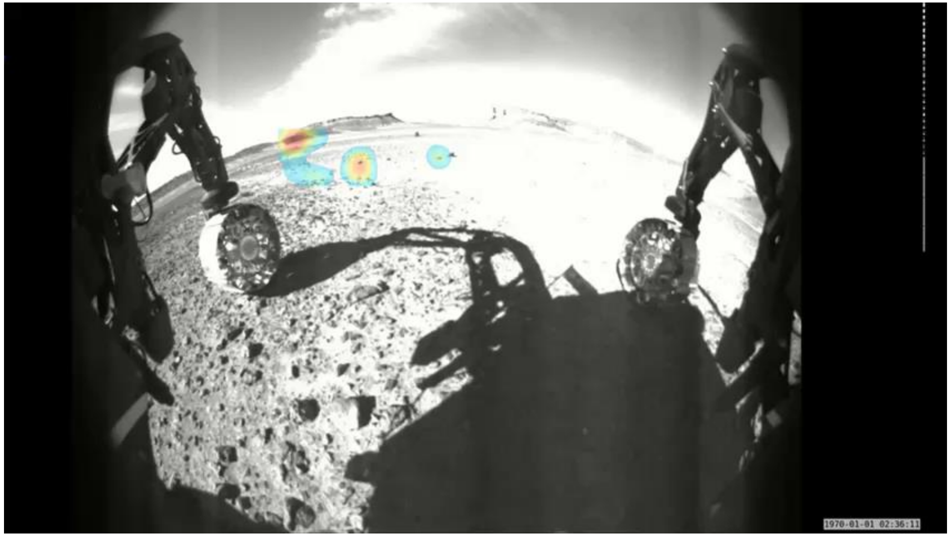
PLANETARY DEMONSTRATION: AUTONOMOUS ROVER (1)

Orbital scenario:

- ❑ MSR-like scenario

Objectives (results):

- ❑ Autonomous Long Traverse (1.38 km in 8,5 hours)
- ❑ Average planning time (9s)
- ❑ High-level goal commanding (39 plans generated)
  - **"take image (position, head, pose, time)"**
  - **"take sample (position, time)"**
  - **"downlink (time)"**
  - **"scanFor (event, area, time)"**
- ❑ Dynamic re-planning (Opportunistic Science)
- ❑ Dynamic re-planning under errors while executing
- ❑ E1-E4 commanding



PLANETARY DEMONSTRATION: AUTONOMOUS ROVER (2)

- The Mission Planner generated sub-optimal plans.
- The current policy of discarding goals when there is no planning solution is not optimal
- The scientific agent was constantly adding new goals to be accomplished generates a rather large number of false positives that are given as goals to Mission Planner. In consequence, the rover could be blocked for large amounts of time due to continuous re-planning.
- While Rover Guidance was able to perform a 1.4km autonomous traverse, this could be further improved by parallelizing computations and therefore reducing the number of stops.

Metric	Description	Value
RT	Total running time	9h39min
CD	Estimated distance covered in autonomous mode	1396m
MS	Number of goals accomplished in E4	10 goals
PMS	Ratio of accomplished/ total goals in E4	41%
APT	Average planning time	9.07sec
SDPT	Variance of the planning time	9.65sec
NIG	Number of images analysed by GODA	285 images
GGFDR	Ratio false positive goals/total number of goals generated by GODA. (Parameterized by *P*, minimum classification probability set by experts)	11.7% ($P \geq 0.8$)
		27.2% ($P \geq 0.6$)
ATSR	Ratio average navigation speed / maximum rover speed	0.32m/sec
AP	Average speed for approaching targets	0.048m/sec

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DEMONSTRATION PLANETARY FIELD TESTS

The rationale for the Erfoud, Morocco Tests was to perform the final tests with the real SherpaTT rover and to perform the formal validation test of the components listed below. Final tests are thought to intensively test the whole system in a realistic environment so to be able to detect and fix errors or problems that do not occur in simulated or more controlled environments.

- ❑ The ERGO Agent, focusing on the correct integration of the following reactors:
  - ❑ Ground Control Interface,
  - ❑ Command Dispatcher Reactors,
  - ❑ Planner Reactor and
  - ❑ GODA Reactor.
- ❑ The objective was to test that the Agent was able to communicate with the functional part and to command the Sherpa rover through all autonomy levels (E1, E2, E3 and E4).

TEST BATTERY IN MOROCCO FIELD (1)

Nominal E4 mission with three different goals:

To demonstrate how ERGO is operated in E4 autonomy level under nominal conditions but with limited distances travelled, producing a plan based on three goals and executing it nominally. A File containing E4 goals will be sent simulating Ground at the beginning of the sol. The rover will build a plan, execute it, and provide the TM files containing the results.

Nominal E3 mission with long traverse:

To demonstrate the capabilities of Rover guidance to reach a 1km traverse in the scenario. The rover is loaded with a set of traverse goals to traverse 1 km. The scenario is aimed to verify that the rover is able to traverse this distance during the designated time.

E4 replanning due to target destination not reached within deadline:

To demonstrate how ERGO is able to cope with errors in the planning, and the planner is able to re-plan dynamically discarding non achievable goals.

E4 Mission with opportunistic science:

To demonstrate how GODA is able to detect scientific events and how ERGO can handle the appearance of serendipitous goal opportunities or errors by means of re-planning in E4 autonomy level. A goal will be sent to the GODA reactor to detect serendipitous events. GODA will inject new goals to force the system to perform re-planning. To define relevant science targets to be identified by the science detector component or errors originated in the different layers of ERGO or due to the environment that will halt the execution and request the plan to be fixed.

TEST BATTERY IN MOROCCO FIELD (2)

E4 Mission with errors (FDIR):

To demonstrate how ERGO can handle HW errors and verify robustness. A disconnection error will be injected. It will be detected that the rover goes back to waiting for further instructions

Mission with multiple autonomy levels (single/multi sol):

To demonstrate how ERGO is operated in multiple autonomy levels under the presence of errors on the long-range mission scenario. Levels E3, E2 and E1 will be tested in this use case.

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TEST BATTERY IN MOROCCO FIELD (3)

Data	Value
ERGO Agent working	136982 TICKS (38 h 3 min 2 sec), 4+ kms
Autonomy Level E1 Time	27124 TICKS (7 h 32 min 4 sec)
Autonomy Level E2 Time	4950 TICKS (1 h 22 min 30 sec)
Autonomy Level E3 Time	72315 TICKS (20 h 5 min 15 sec)
Autonomy Level E4 Time	32593 TICKS (9 h 3 min 13 sec)
Stella Planning	240 sessions, 221 plans provided, 45+ min. of replanning time
Total Goals Dispatched	1804

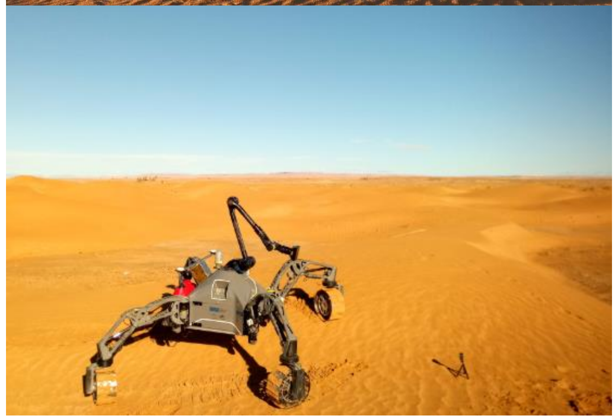
PLANETARY TESTS (VIDEO)

(courtesy DFKI)

ACHIEVEMENTS IN THE MOROCCAN TEST FIELD

The outputs of this test campaign can be summarized as follows:

- The Agent proved to be a reliable system in all autonomy levels (E1 to E4) and proved to be able to work continuously for hours.
- The integration of the system using TASTE and parts of OG1 (OBCPs) evidence the ease to fully integrate ESROCOS in future iterations.
- It is possible to use a scientific agent to be able to detect serendipitous and interesting events in the environment and to modify, fully autonomously, the plan to investigate them.
- As future enhancements the planner can take better decisions when discarding goals using the information from the failure (from stellar planner). The planner can also adapt the planning time based on the number of goals that are to be included into the plan.
- Guidance was able to traverse more than the kilometers expected in the long traverse test. It is a good point from which to enhance the integration and state machine to allow longer planning, cancelling of the planning session and a way out of safe status among other features.



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END OF THE PROJECT

After 27 months of work, ERGO came to an end in January, 2019

ERGO held its Final Presentation at GMV premises, where REA, PSA and all the partners of the consortium reviewed all the projects results, the advances w.r.t state of the art, the tests and the conclusions.

The ERGO system will be reused in several projects of the second phase of PERASPERA project… so the ERGO story doesn't really come to an end, rather it is to be continued in…

ERGO IN THE PERASPERA 2ND CALL

- **EROSS (OG7):** on-orbit servicing spacecraft (chaser) to perform rendezvous, capturing, grasping, berthing and manipulating of a collaborative client satellite (target) provisioned for servicing operations including refuelling and payload transfer/replacement.
- **PULSAR project (Prototype for an Ultra Large Structure Assembly Robot – OG8),** led by Magellium has as an objective the development of a demonstrator for the robotic in-orbit assembly of a large composite structure, in particular a tiled telescope mirror.
- **MOSAR (Modular Spacecraft Assembly and Reconfiguration – OG9)**, led by Space Applications Services, is to develop a sound technology demonstrator of on-orbit modular satellite reconfiguration relying on robotic capabilities
- **ADE project (Autonomous Decision Making in Very Long Traverses – OG10)** aims to develop and test in a representative analogue a rover system suitable to increase data collection, perform autonomous long traverse surface exploration, guarantee fast reaction, mission reliability, and optimal exploitation of resources.
- **PRO-ACT project (Planetary Robots Deployed for Assembly and Construction Tasks – OG11)** establishment of a precursor lunar base with essential capabilities in preparation to commercial exploitation of in-situ resources

CONCLUSIONS (1)

- ERGO is the 2nd Operational Grant of PERASPERA's 1st call - aimed to design and development of On-Board Autonomy Framework, with the following objectives
  - Goal commanding
  - On-board Dynamic replanning
  - Opportunistic science based on on-board images
  - Autonomous Guidance and Motion Planning (robotic arm)
  - ERGO uses a model-based approach by using TASTE
  - ERGO uses Formal verification and validation techniques using BIP
- It has been applied successfully to a planetary and an orbital use cases
- ERGO is being used and extended in the 2nd PERASPERA Call (from OG7 to OG11) applied to different applications together with the outcome of OG1 to OG5

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CONCLUSIONS (2)

- The capabilities of the ERGO framework make it suitable for future use in space missions in which a high level of autonomy will be required. Its capabilities are also ideal for terrestrial applications in specific markets (nuclear dismantling, oil and gas inspection, biohazard environments, SAR, ...)
- The PERASPERA2's ADE project will further extend and prove the ERGO capabilities
- For more info:
  - http://www.h2020-ergo.eu and http://www.h2020-ade.eu
  - Email, of course

THANK YOU

Jesús D. Jordán, jdjordan@gmv.com