# FP7-SPACE PROVISCOUT – PLANETARY ROBOTICS VISION SCOUT


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ABSTRACT

The FP7-SPACE Project ProViScout (scheduled from April 2010 to September 2012) aims to demonstrate the feasibility of vision-based autonomous sample identification & selection in combination with vision-based navigation for a long range scouting/exploration mission on a terrestrial planet along with the robotic elements required. The paper gives an overview of the PRoViScout technical, strategic and scientific objectives along with solutions, and documents detailing the project status after one third of project duration.


## 1. INTRODUCTION

Mobile systems are among the most critical of all space missions. In future the number and variety of such platforms will require more autonomy than is feasible today [5], particularly in the **autonomous on-site selection of and access to scientific and mission-strategic targets**. The combination between science-driven and operations-driven decisions taken on-board is a key component of this autonomy.

PRoViScout establishes the building blocks of such future autonomous exploration systems in terms of robotics vision (and decisions based thereupon) by a decision – based **combination of navigation and scientific target selection,** and integrating them into a **framework ready for and exposed to field demonstration**. The **main PRoViScout objectives** can be summarized as follows:

1) Include the **search for scientifically interesting targets** as an essential component for mission success into the navigation chain by **Autonomous Tasking** (Goal based **planning and re-planning**).
2) Populate a robotic **vision on-board processing chain (PRoViSC)** with essential components already available at the proposing institutions, with minor adaptation and integration effort.
3) Address and merge a **representative set of sensors** (including a novel zoom 3D-Time-of-flight camera) to fulfil important scientific objectives and prove the general applicability to the approach in different mission scenarios.
4) Compile a **PRoViScout Demonstrator on a mobile platform** that combines sensors, processing and locomotion on-board ready for an integrated outdoor demonstration.
5) Integrate a **monitoring function (PRoViM)** to understand the behaviour of the system in operation.
6) Demonstrate the **feasibility of long-term vision-based scouting** making use of a representative outdoor test bed and the PRoViScout Demonstrator platform.

## 2. PROJECT STRATEGY & LOGICS

Until end of 2010 the European Community's Framework Pogramme 7 (FP7) has launched four calls in the SPACE domain. PRoViScout was submitted to the second call end 2008, emphasizing on the following call objectives (among others):

- Main addressed call topic: "Space Exploration"
- Optimum preparation of scientific payloads
- Effective scientific exploitation of future space missions data
- Enhance effectiveness & productivity in usage of data, including archived data
- Improve capabilities to move, to select and collect and finally return samples to Earth
- Increase public awareness
- Complementary and in close co-operation with ESA

In complement to mission-specific or technology driven ESA programmes, PRoViScout was designed as a mission-independent study, to demonstrate the feasibility of a new concept that will be vital to future robotic planetary surface missions. Building on several recent and ongoing FP7, ESA and national studies conducted by the PRoViScout participants (EUROBOT EGP [1], PRoVisG [2], CREST [3], or ExoMars [4] [17]), several building blocks can be re-used by PRoViScout with minor modification, hence transferring effort from basic development to integration and scenario aspects. The main effort in PRoViScout is therefore more or less evenly distributed across seven work packages:

**WP1 MANAGEMENT:** This standard project component - includes the administrative (Task T1.1), financial (T1.2), technical (T1.3) and scientific (T1.4) management of the project.

**WP2 CONSOLIDATION:** To formulate the Road Map, WP2 summarizes the status of knowledge about the topics covered in PRoViScout and states the requirements in terms of science (T2.1) and operational aspects (T2.2). System requirements for the final demonstrator are formulated (T2.3), the demonstration scenarios and target missions are collected (T2.4), and relevant computer vision in terms of recognizing scientific targets is addressed (T2.5).

**WP3 SCIENCE TARGET SELECTION:** This work package addresses the science selection element of the architecture and includes: Geological and Morphological classification implementation (including aerial) (T3.1), Organics and Biological classification implementation (T3.2), and the low-level selection of interesting targets coupled directly to the Pan-Tilt control of the Rover vision system ([6]; T3.3). Pattern Recognition and Learning to train and select the image primitives of scientific targets detected from T3.1 and T3.2 is implemented in T3.4.

**WP4 PROVISC & ON-BOARD SYSTEM:** This is the main system integration work package that enables an operational vision-based navigation and control of the rover for an end-to-end demonstration. Multi-spectral panoramic camera, the 3D-TOF sensor, high resolution camera and WALI (a novel Wide Angle Laser Imager [8] [9]; T4.1) and an Aberystwyth University (AU) Rover (T4.2) are adapted. The Navigation and Mapping Module (T4.3) as well as the Decision Module (T4.4) are plugged in. All modules are integrated into a Software Framework (T4.5) executable on a processing unit on board of the Rover. Supporting 3D Vision functionalities such as calibration, vision data fusion and 3D reconstruction are covered in T4.6.

**WP5 PROVIM:** The monitoring and visualization of the rover operations and its decisions is realized in this WP, with the monitoring of operations and decisions (T5.1), visualization and rendering of special components (T5.2), and the backend interface to the internet (T5.3).

**WP6 SIMULATION & TESTING:** All simulation and testing, except the final public test, takes place in this Work Package. A simulated data base is provided by T6.1 in order to have ground-truth whenever needed. Special attention is paid to the feasibility of merging aerial / aerobot with ground – based data, which is performed in T6.2. A sequence of laboratory tests (T6.3) should ensure the proper function of individual components and the interfaces between them. A contribution to the international series of AMASE field-tests [10] at the Arctic region is covered by T6.4. Mars Exploration Rover (MER) 3D vision processing (T6.5) is used to verify the methodology using real comprehensive data from a planetary surface, to show the benefits of the autonomous science selection approach and its applicability in planetary environment. An internal test with all components integrated (T6.6) should verify the whole Software – and Hardware suite.

**WP7 EXPLOITATION:** T7.1 is concerned with the academic and public dissemination of PRoViScout results, closely synchronized with the European Spacemaster Initiative [11]. One major Project output is the integrated public test (T7.2). Spin-offs are evaluated in T7.3, and the external PRoViScout web-site is compiled and maintained in T7.4.

In contrast to many ESA studies, PRoViScout combines components of different maturity / technological readiness levels. The major output will be feasibility of the whole decision-based scouting concept, based on an integrated demonstration.

## 3. EMPLOYED RESOURCES & EXPERTISE

The entire PRoViScout effort is planned with about 210 Person Months. It comprises 6 milestones of which one has been successfully achieved by end of 2010.

In addition to the 11 PRoViScout Beneficiaries (Table 1) the Consortium is supported by the Machine Learning and Instrument Autonomy group of JPL (Robert Granat), acting in the Steering Committee together with scientists from some of the PRoViScout Partners. The tasks are well balanced between the academic, research and industrial partners.

| Institution | Main Contribution |
|---|---|
| Joanneum Research (JR), A | 3D Vision, Classification |
| SciSys UK Ltd. (SSL), UK | Autonomy Architecture, , Science assessment |
| German Aerospace Center (DLR), D | Planetary Science |
| Aberystwyth Univ. (AU), UK | Platform, vision, robotics |
| Czech Technical Univ. (CTU), CZ | 3D Vision |
| GMV, E | Navigation |
| University of Leicester (ULEIC), UK | Science |
| Swiss Center for Electronics and Microtechnology (CSEM), CH | Sensors |
| TraSys (TRS), Belgium | Simulation |
| University College London (UCL), UK | Science & Sensors |
| Univ. of Strathclyde (UoS), UK | Decision module |

Table 1: PRoViScout participants and contributions

## 4. TECHNICAL AND CONCEPTUAL OVERVIEW

The on-board components can be divided into two categories, namely *PRoViSC*, implementing relatively high level functionality, and *Platform*, communicating directly with the hardware (Figure 1). Together, along with the PRoViM element they form a complete end-to end autonomy architecture for future rover concepts.

**PRoViSC** consists of Mission Management components such as the Executive, the MMOPS (Mars Mission On-Board Planner and Scheduler [17]), a science assessment module, and the navigation & vision processing modules. The **Platform** consists of the Rover together with the sensors and sensor pointing devices. For a more detailed description of the hard-and software architecture see [15].

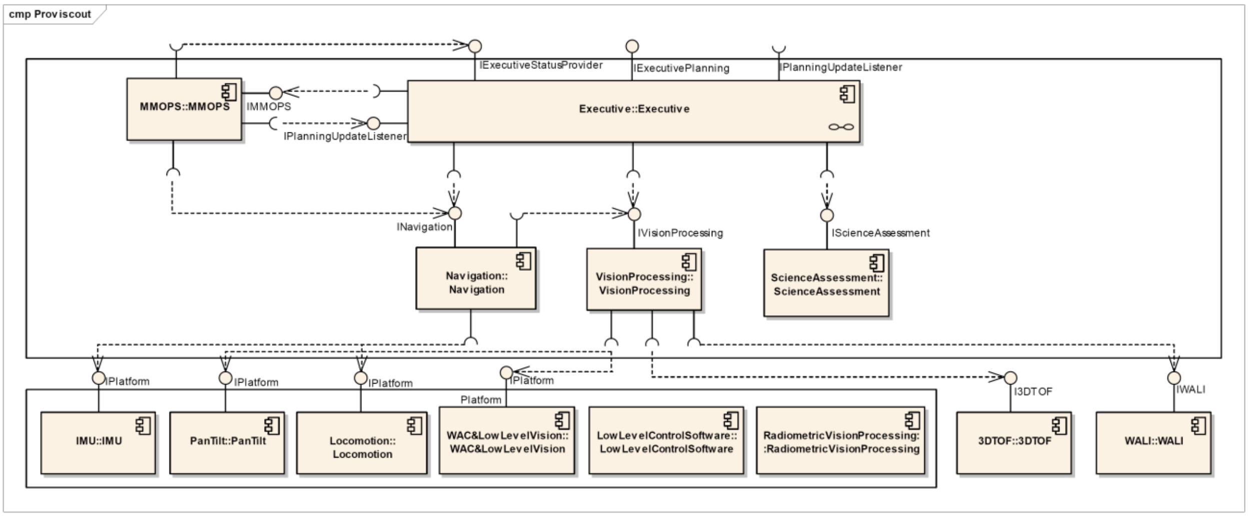


Figure 1: PRoViSC & Platform Logical Architecture

The **Executive** has two main purposes:

- Act as an interface between the PRoViM Operations element and the Rover. This includes providing status/monitoring information such as rover position and timeline status to PRoViM, and receiving plans and science templates from Overseer and forwarding these to MMOPS for possible insertion into the plan. It can therefore be used to support fully autonomous operations whilst also allowing real-time monitoring and control.
- Maintain a model of the onboard plan as prescribed by MMOPS and execute this at appropriate times.

Tasks that can be executed by the executive include:

- Navigation/Traverse
- Acquire RGB - using 3D TOF's RGB camera
- Science Assessment (RGB) - assessment of science from RGB image data
- Acquire High Resolution Image
- Acquire WAC Image
- Acquire 3D TOF
- Replan

**MMOPS** will be relied upon to update and ensure the consistency of the mission timeline and provides deliberative, high-level mission management capability. In addition to receiving an initial plan, it will receive requests to add navigation tasks and science opportunities to the timeline. Before doing so it will ensure that there are enough resources (time, power, memory) for continued operation using static and dynamic information.

Timeline validation and repairing (as required) will also occur periodically to ensure correct operation of the rover. Depending on the type of sub plan currently executing, task failures/overruns will be treated differently. For example, if a science opportunity sub plan fails, this will simply be removed and execution continues as normal. If a navigation task fails it might be possible to recover if there is a task overrun and there is no restriction on time.

In order to fulfil science autonomy requirements, a number of **Science Assessment components** will be available to analyse images taken using cameras onboard the rover. Although these will implement a different set of algorithms, these will all need to identify features such as structural layering, compositional layering, cross bedding and slumped structures.

As part of the science assessment tasks, the science assessment component will use a DEM to determine the location of a target in 3D space, and determine the most appropriate coarse waypoint from which to perform the next level of science.

Several implementations of the Science Assessment component will be produced, all implementing the same interface in addition to a façade component, also implementing this interface. All access to the Science Assessment component is made through this façade, which will be able to query each implementation for

inputs and apply various weightings to these where appropriate.
Science assessment and MMOPS are in more detail addressed in [15].

The **Navigation component** will be in charge of instructing the Platform to move the rover from one location to another. This typically will invoke the vision processing module (see below) to take 3D TOF images and construct a DEM, and combining this with mechanical odometry and IMU readings to determine current location and produce a series of internal waypoints required to traverse to the destination.

**Vision Processing** (see Table 2 for its interface as example) will provide a set of utilities to perform various functions involving imagery, including:

- Image acquisition: 3D-TOF, RGB, WAC, WALI, ..
- Mapping (DEM generation) from 3D-TOF vision data
- Construction of a panoramic image from the WAC
- Reconstruction of stereo imagery from WAC (if stereo is applicable)
- Generation of hazard and slope maps from DEM
- Calculation of visual odometry for use in the navigation component
- Maintenance of a global map.

| Function | Description | I/O |
|---|---|---|
| Create Local DEM | Acquires a set of 3D TOF images covering the specified ROI and constructs a local DEM from this. | ROI [in]<br>Rover Position, Attitude [in]<br>DEM / Ortho / Slope Map / Roughness Map / Hazard Map Descriptor Filenames [in] |
| Acquire Pano ramic | Acquires a set of RGB images covering the specified ROI and constructs a panoramic image from this. | ROI [in]<br>Panoramic Image Descriptor Filename [in] |
| Acquire VO | Consecutively acquires RGB images and determines positional offsets by tracking features. | Pan, Tilt [in]<br>Rover Position & Attitude [in]<br>Rover Position & Attitude (updated) [out] |
| Hazard Map | Consecutively acquires 3D TOF images and constructs low-resolution hazard maps. | Pan, Tilt [in]<br>Low Res Hazard Map [out] |
| Target Locali sation | Determines 3D coordinates of a ROI in image space (as detected by science assessment).<br>Function will implicitly acquire 3D TOF imagery if not available (→ update of Global Map). | Image Pan, Tilt [in]<br>Image Rover Position & Attitude [in]<br>ROI in image space [in]<br>3D coordinates of ROI [out] |
| 3DTOF | Moves the PTU to the specified position and acquires a 3D TOF image from the platform. | Pan, Tilt [in]<br>3D TOF Image Descriptor Filename [in] |
| RGBIm | Moves the PTU to the specified position and acquires a RGB image from the platform. | Pan, Tilt [in]<br>RGB Image Descriptor Filename [in] |
| 3DTOF & RGB | Moves the PTU to the specified position and acquires a 3DTOF and RGB image from the platform. | Pan, Tilt [in]<br>3D TOF & RGB Image Descriptor Filename [in] |
| WALI Image | Acquires an image from WALI. | Pan, Tilt [in]<br>WALI Descriptor Filename [in] |
| Get GMap | Returns the current global map. | Filename [in] |
| Reset GMap | Resets the global map for a new scenario/test run (e.g. when a new plan is submitted to the Executive) | |
| GMap Merge | Merges specified DEM / Ortho / Maps (e.g. from Satellite or Aerobot) into the Global Map. | DEM / Ortho / Maps [in]<br>Global Map [in] (updated) [out] |
| addGlobalMapListener | Adds a listener for receiving updates to the global map. | Listener [in] |
| removeGlobalMapListener | Removed a global map listener | Listener [in] |

Table 2: PRoViSC Vision processing interface

The **Rover Platform** component, in its simplest form, provides an abstraction to the low level functionality specific to the platform. This includes access to:

- A Pan/Tilt unit mounted on the mast
- A Wide Angle Camera system, comprised of two cameras with R, G, B filters. 12 geology filters are also provided and spread between cameras (i.e. 6 geo filters per camera). Nominally full 360x180 panoramic imagery can be produced on all available wavelengths taken at each coarse waypoint, although it is possible to specify more limited angles and only in RGB

- A 3D Time of Flight camera with RGB capabilities - nominally full 360x180 panoramic imagery taken at each navigation step, although it is possible to specify more limited angles, zoom and RGB/3DTOF only
- A Wide Angle Laser Imager (WALI) - obtained once a target has been identified by the science agent, pointed towards the target[1]
- The Locomotion subsystem
- (Potentially) A Hyper Spectral Imager.

The system will consist of the following **primary pieces of hardware**:

- A rover platform provided by AU with on-board computer
- Linux laptop(s) with a sufficient processor for Vision Processing/Science Assessment and some USB ports.
- WALI mounted on the platform, connected to the laptop (TBD)
- 3DTOF (incl. RGB Imager) mounted on the platform's pan/tilt unit, connected to the laptop

## 5. DEVELOPMENT STATUS SPRING 2011

By paper submission PRoViScout has been running for 12 Months. Beside the written deliverables (design documents and reports, partly available from the PRoViScout Web Site [7]) the main results achieved so far are as follows:

- All requirements from science and operations have been collected and reported. This includes the definition of the target scenario planned for the field test during the final Project phase.
- System design has been finished. All interfaces between the components (rover, vision system, Hardware trade-offs, navigation system, decision module, execution control, and monitoring system) have been defined, and the main functions as well as distributed and shared data have been identified & reported in a design document.
- The new 3D-TOF camera (Figure 2) has been designed and prototyped by CSEM, which is able to zoom, and integrates RGB high-resolution images.
- Preliminary tests to extract scientifically interesting image parts from training & classification indicate that an automatic system is able to detect meaningful targets.
- Candidate field test sites in Morocco, Tenerife, Wales and Iceland were investigated, assessed and discussed. The major result is a strong preference towards Tenerife, due to accessibility, logistics, locomotion, climate and scientific aspects.

[1] By time of paper writing, the WALI is designed to be used off-line as post-demo fusion experiment.

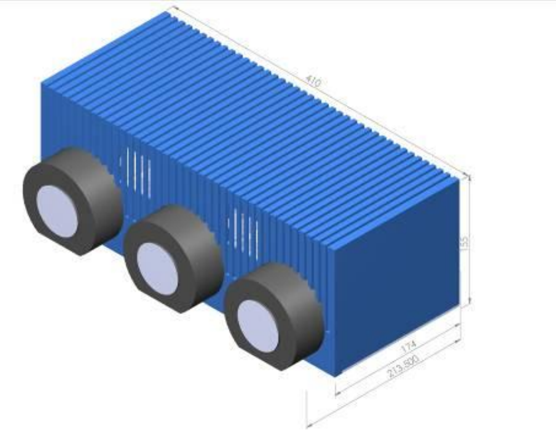

Figure 2: Dimensional layout of the zoom RGB 3D-TOF camera. © CSEM.

In early 2010 an assessment of scientifically interesting areas at Clarach Bay (Aberystwyth, UK) took place (Figure 3). The resulting report is publicly available via the PRoViScout webpage [7] download area. In January 2011 an aerobot test [16] was conducted, to verify the concept of a tethered aerobot for Rover mapping & science target selection support. The definition of relevant training samples to test pattern recognition methodologies for automatic identification of scientifically interesting targets is ongoing. Key parameters for the operational scenario of the final field test have been assessed, and some recently implemented components have already been verified (Figure 4). Independently, components such as 3D reconstruction of the rover's environment [12] [13] or specific target recognition [14] have started to develop.

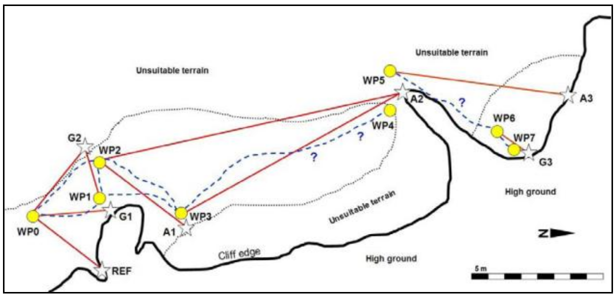


Figure 3: Example for waypoints and a globally planned rover trajectory in the area of Clarach Bay (Aberystwyth, UK). © Univ. Leicester.

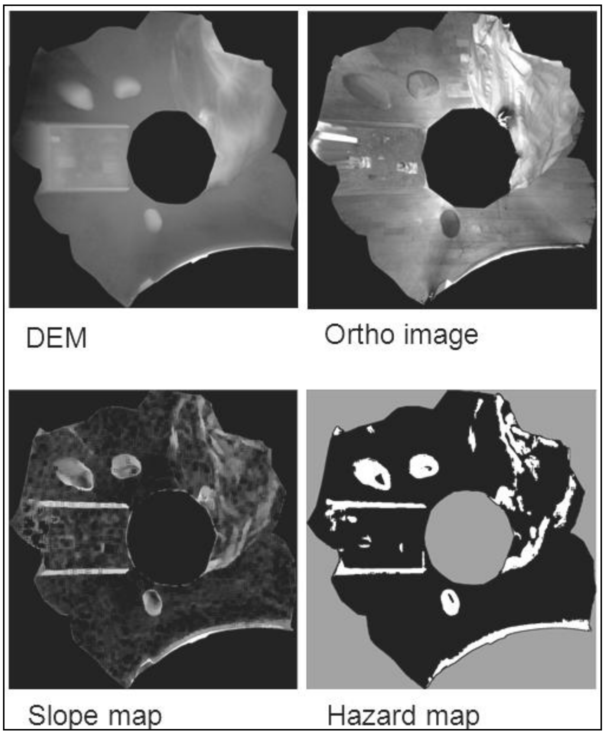

Figure 4: Mapping products from 3D-TOF imagery.

## 6. FORTHCOMING WORK

Following the completion of requirements specification and system design the PRoViScout Team will now proceed with software and hardware integration. Starting in Summer 2011, key software components are to be further developed to realise the proposed autonomy concept. This will be followed by mechanical & electrical integration to permit more in-depth sub-system and full system testing.

The current concept consists of 11 major components from 9 different partners and 11 key interfaces with multiple interdependencies. However the focus of the work is on the development of component functionality so the autonomy architecture has been designed to minimise integration effort where possible whilst supporting this advanced autonomy concept. This is reported in a complementary PRoViScout paper in the proceedings of this conference [15].

In the demonstration scenario (autumn 2012, caldera of Tenerife), the Rover control system, equipped with active and passive vision sensors, will receive a local map obtained by satellite and/or aerobot imagery. The map contains waypoints indicating interesting targets. On its autonomously selected path through the terrain the system observes its environment and looks for scientifically interesting targets. Once found a target, it assesses the costs to reach the target and decides upon changing its original plan to obtain close-ups. Mission control receives high-level data only, getting an insight into the decisions of the systems and main parameters involved (images taken, costs, decision reasoning, various visualizations), see Figure 5 for an example.

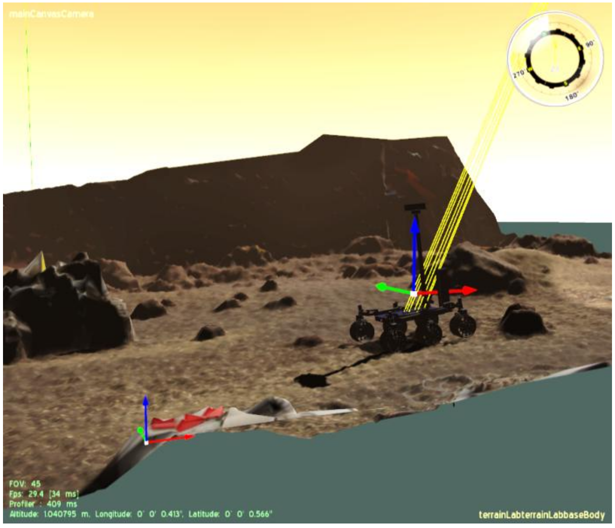
Figure 5: Visualization of the robotic system inside its environment as planned during the field test, considering the terrain, the sun position, real-time shadows, the display of system key parameters and a rover simulation. © TraSys.

## 7. DISCUSSION & CONCLUSIONS

ProViScout supports the development of **more autonomous space vehicles**. Vision based sample identification enables such rovers to act more independently, which is needed for more efficient scientific mission outcomes. The PRoViScout project objective is to **increase the amount of quality science data** that remote planetary rovers can deliver on behalf of Earth based science teams. This will be obtained by prototyping intelligent technologies which increase their autonomy and therefore exploration efficiency.
The major project goal is a **field test** that demonstrates the ability to autonomously traverse terrain whilst "keeping an eye open" on potential scientifically interesting targets passed on its way – and change the global plan in favour of additional observations.

The first year of the Project has paved the way to such a system by identifying the key parameters of a scenario, specifying the system components and their interfaces, and already detailed designing and implementing major components such as a novel 3D-Time-of-Flight sensor, and aerobot mapping strategies.

PRoViScout will effectively **increase the amount of data returned per Euro spent** on European space missions thereby ensuring good value for European Taxpayers.
Given the strong participation and investment from

several industrial but non-prime, space companies in the project, there is also a focus on identifying practical routes to technology infusion in forthcoming missions. The proposed architecture has been developed with concepts such as adjustable autonomy in mind which will smooth this transition. Some components have already been used to craft the autonomy concepts for ExoMars such as the MMOPS initiative in phases A and B of the mission. As the project progresses, various elements of the work will be evaluated for relevance to mission such as a Sample Fetching Rover.

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