# Moonwalk – Human Robot Collaboration Mission Scenarios and Simulations

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SPARTAN SPACE

# Moonwalk – Human Robot Collaboration Mission Scenarios and Simulations


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**This paper describes simulation mission scenarios which focus on human-robot collaboration. Further, it explains the technologies developed for project Moonwalk and describes possible evaluation methods to be able to evaluate the outcome of two trials in different environments, one reflecting a Lunar and the other, a Martian environment. Moonwalk develops new, practical methods for the interaction between astronauts and robots. In earth-analogue simulations of missions to Moon and Mars, one of the challenges is the simulation of operational constraints such as the reduced gravity or the communication delay between the astronauts and mission control on Earth. In project Moonwalk, two analogue simulations are planned for the conditions that astronauts will encounter during future extravehicular activities (EVA) on planetary surfaces: firstly, simulations subsea and offshore the coast of the French city of Marseilles will be conducted, where an EVA on the lunar surface under reduced gravity will be performed. A second simulation will be conducted in the Spanish region of Rio Tinto (an established Martian analogue site), where operations are focusing on exobiological sampling and sampling procedures under extreme environmental conditions. For these simulation missions specific scenarios for human-robot collaboration have been developed to be performed, compared and evaluated.**


## I. Introduction

MOONWALK, as an inspirational name, stands for Technologies and Human-Robot Collaboration for Surface EVA Exploration Activities and Training in European Analogue Environments is an EU co-funded space research and development project under the 7th Framework Programme. It was commissioned in September 2013. Under the lead of the German Centre for Artificial Intelligence (DFKI) 7 partners collaboratively work on technology development of a rover, a simulation space suit, an EVA information system, a Mission Control Center and astronaut simulation tools including their testing in field trials and the analysis of the outcome. The consortium comprises:

- German Research Centre for Artificial Intelligence (DFKI), Bremen, Germany, coordinator
- COMEX SA, Marseille, France, technical coordinator
- Space Applications Services N.V. / S.A., Zaventem, Belgium
- LIQUIFER Systems Group GmbH, Vienna, Austria
- Airbus Group Innovations, Newport, UK
- NTNU Centre for Interdisciplinary Research in Space, Trondheim, Norway
- Instituto Nacional de Técnica Aeroespacial, Madrid, Spain

The project's duration is three years and it will conclude in August 2016. Specific scenarios designed to highlight the capabilities of human-rover interaction during the exploration of extra-terrestrial surface missions have been developed. The focus of the tested scenarios is on an astronaut and the small Asguard rover communicating via gesture control while scouting, traversing and sampling in unknown and challenging terrain. The scenarios will be tested in two exemplary simulations, one off the coast of Marseille, France, simulating 1/6th gravity and lunar exploration and one in Rio Tinto, Spain, simulating a Martian surface mission.

The paper describes the simulation environments and the scenarios to be tested in these. The main components of these simulations are the Asguard rover, the enhancement of Comex's Gandolfi-2 simulation space suit, the EVA information system (HMI), and the mission control center, all integral part of the mission scenarios. The gained knowledge from the simulations will be evaluated specifically with regard to performance and psychological impact of work in such teams. Through a special announcement of opportunity related to the two simulations the Moonwalk team also seeks to connect to the international research community of collaboration.

## II. Simulation Environments

Two different simulation environments will be used to test the equipment and procedures developed for Project Moonwalk: the Marseilles Bay Subsea Sites and Río Tinto (southwest Spain). Both environments have been previously established as relevant astrobiological analogues (Amils et al., 2007; Weiss et al. 2012) and offer similar terrains and, to a large extent, similar challenges to those occurring on Lunar and Martian surfaces.

The Marseilles Bay Subsea Analogue Sites offer the chance to simulate EVA operations in a remote, stressful and reduced gravity environment, such as the Lunar surface. Several training sites including various different terrains (sand/rock plains, lava tubes, caves, canyons) have already been identified (Weiss et al. 2012), allowing us to devise several low gravity mission scenarios (see below). Furthermore, all the identified locations can be either accessed onshore, or can be easily reached by a vessel, greatly facilitating logistics and reducing the cost with respect to EVA simulation.

The Marseilles Subsea Analogue will be used to simulate geological field exploration and EVA operations, putting emphasis on the testing of procedures and technologies for communication, robot control, human-robot interaction, information and control systems.

The Río Tinto environment has received increasing interest over the last two decades due to it's unique geochemical and mineralogical conditions, which makes it the largest and most representative Mars analogue on Earth (Amils et al., 2007). The discovery of jarosite, a ferric iron sulphate-hidroxide mineral, on the Martian surface at Meridiani Planum (Klingelhöfer et al., 2004) placed a particular constraint in the interpretation of Mars paleo-environment, as said mineral is considered to precipitate only in acidic conditions (Bigham et al., 1996). Its presence requires a wet, oxydizing and acidic environment in early Mars, albeit its persistence over time suggests that, following jarosite formation, arid conditions prevailed (Madden et al., 2004). Jarosite, as well as other characteristic minerals such as goethite and hematite, are abundant in the Tinto basin as a result of the activity of chemolithotrophic microorganisms that thrive in the high concentration of iron sulphides of the Río Tinto area (Fernández-Remolar et al., 2005). The fact that such Martian-like mineralogy is produced by microorganisms makes Río Tinto an excellent proxy for the study of exobiology, as a hypothetical past or present Martian biosphere could rely on similar processes for energy production.

The Río Tinto campaign will be entirely dedicated to the refinement of search procedures for signs of life during future surface EVA on Mars. The project will develop and refine methodologies to detect life forms in extreme environments in conditions that are similar to those observed on Mars and eventually the Jovian moon Europa.

Taken together, both analogue environments complement each other's shortcomings: the Marseilles analogue allows recreation of low gravity, but water results in limited mobility, specially at high speeds, and also precludes radio communication. On the other hand, partial gravity can not be simulated in the Río Tinto analogue, but mobility and radio communications will be similar to those expected in an actual EVA mission on a planetary body.

## III. Scenarios

Specifically for Moonwalk scenarios have been developed which show how a small rover like Asguard can become a partner to the astronaut in field exploration. The overall goals are to *simulate* exploration missions for the moon and for Mars. Safety and science are key objectives with these simulation missions. How to establish a safe base for investigation, search for resources, and do scientific work define the EVA (Extra Vehicular Activities). Hence, the work to be done to achieve the goals and objectives include scouting, mapping, digging, scientific measuring, exploring interesting terrain and sampling. (See Figure 1)

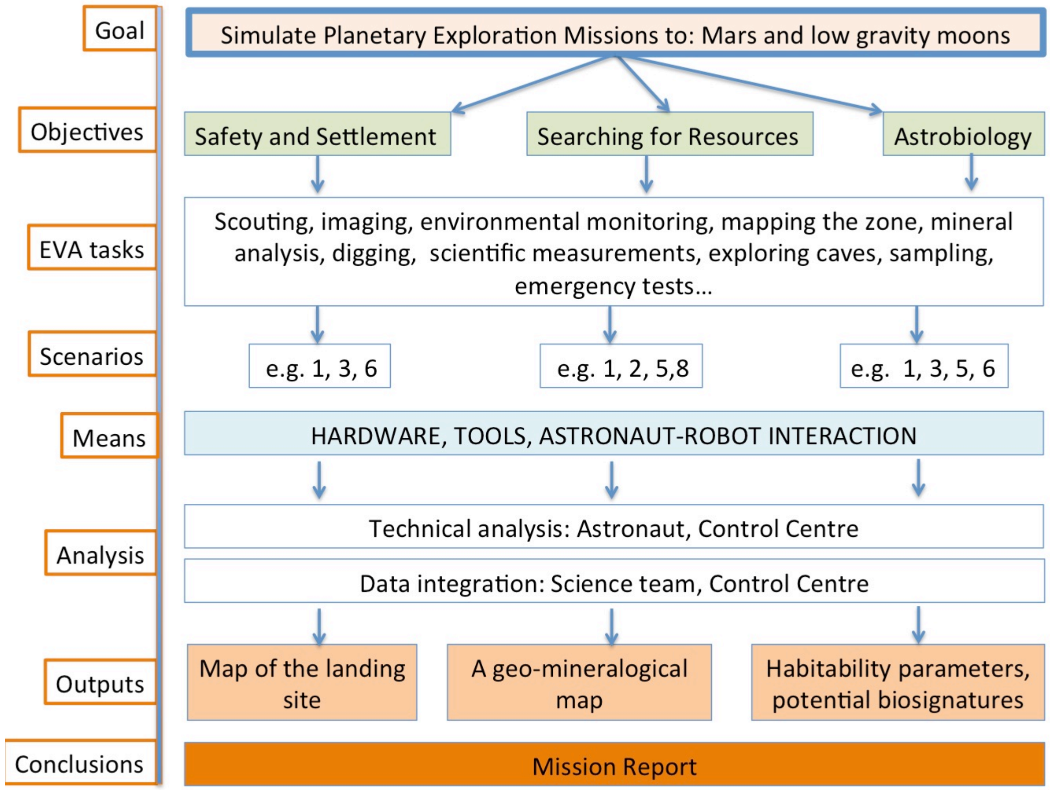



**Figure 1. Scientific approach to developing simulation scenarios.** *Credit: MOONWALK consortium, visualization: INTA, 2015.*

For Moonwalk the Consortium chose to prove such a scientific driven mission simulation with a small rover interacting with an astronaut through gesture control. The following scenarios have been established to demonstrate this Human-Rover interaction.

- Exploration and scouting of a crater including astronaut and a tethered rover: when looking for interesting astrobiological features, one might have to look at terrain which is not easily accessible by humans. A small rover like Asguard can go through rugged terrain and can support the astronaut in scouting and digging in an area where it would be too dangerous for him to go. (E.g. steep slopes, dark shadow zones on case of a lunar environment). This scenario takes the example of scouting and investigating a crater by the rover, delivering and images to the astronaut.
- Astronaut investigates samples while the rover trenches soil: the rover uses its wheel to dig into the soil surface and conveys images to the astronaut. The astronaut can decide whether the rover shall continue, change the spot or retreat.
- Exploration and scouting of a cave including astronaut and rover: a small rover can go into a cave inaccessible for humans and scouts for scientific interesting spots
- Astronaut receives information from the rover while the rover collects information with a Raman spectrometer in a cave: in this scenario the rover can take measurements with a RAMAN spectrometer,

store the information and convey it to the astronaut at a later stage. This scenario demonstrates that a small rover can act as a “third” arm of the astronaut and even conduct scientific measurements.

- Astronaut and rover construct a tool shed together: when having selected an interesting site the rover can also support the astronaut with light construction work, e.g. building a shelter to store tools or lay out samples.
- Emergency scenario; rover helps the fallen astronaut to get up again by bringing a tool to the astronaut: even in emergency scenarios the rover can aid an astronaut with a stick or other tool to stand-up again when fallen.

All scenarios will be conducted under water in partial gravity in a lunar mission simulation AND in Rio Tinto representing Martian simulation. Further, there will be two simulation suits available in the subsea lunar simulations; therefore, these scenarios will be tested with Astronaut-Astronaut Collaboration in comparison to Astronaut-Rover.

In the Appendix all the described scenarios are given for both simulation sites and the following storyboard represents an example as a showcase of how the team started to develop the activities for the testing of the main technical Moonwalk components. In Figure 2, the interaction of the astronaut with the rover carrying a RAMAN spectrometer, and investigating a cave which is not accessible for the astronaut due to is limited height, represents a possible and realistic scenario which summarizes the complex capabilities of this collaboration.

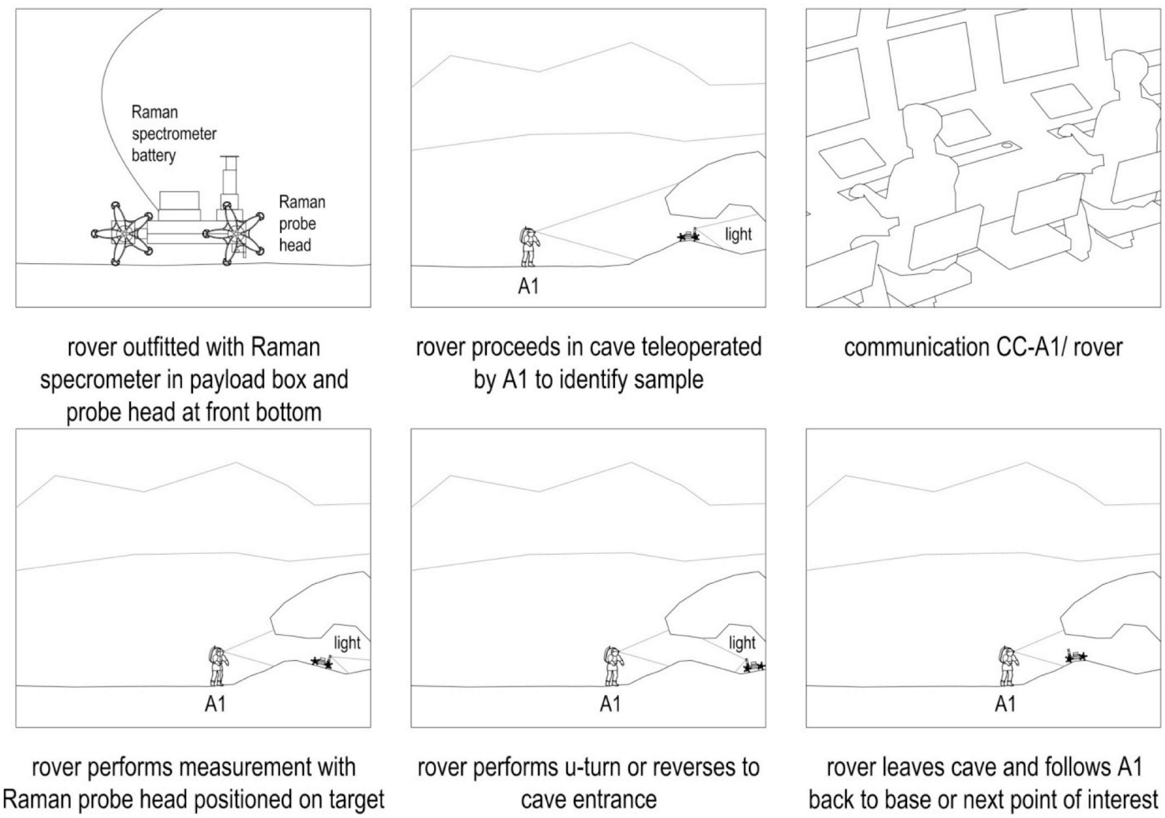



**Figure 2. Astronaut receives information from the rover while the rover collects information with a Raman spectrometer in a cave.** *Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## IV. Main components

The following section presents a more detail look at these main components for which the storyboards were derived. As part of the project Moonwalk all of these components are being specifically developed. The simulations are conducted to test these technologies and thus validate the underlying concept of human-rover collaboration and the needed hardware and software.

### A. ASGUARD

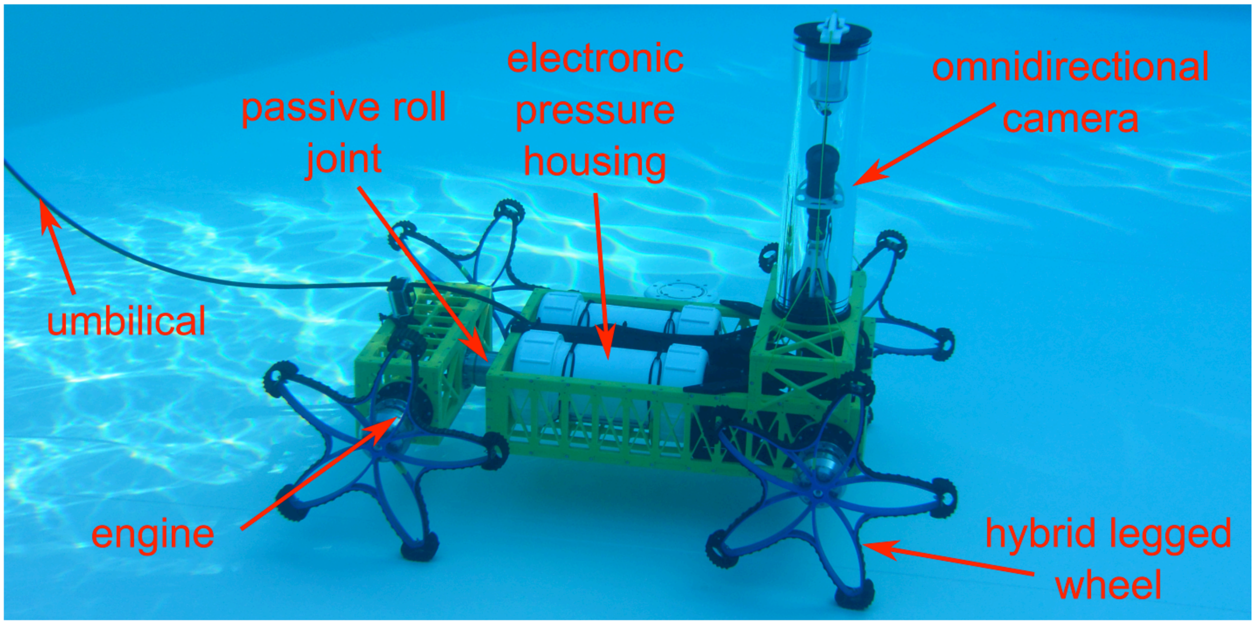



**Figure 3. Pool test of the rover with annotated key elements.** *Credit: MOONWALK consortium, photo: Mathias Höckelmann, DFKI GmbH, 2015.*

The rover's prototype was fully integrated by the beginning of June 2015. Figure 3 shows it during the first pool test for verification of water tightness and function. The key elements of the rover are highlighted. Details of the construction have already been discussed in (Schwendner, et.al. 2015). The engineering test showed the expected performance of the rover. Its buoyancy reduces the weight in water to 3kg from approx. 27kg on land. We expect that the additional weight of the payload does not reduce the performance underwater. In contrast we even expect the additional weight to increase the ground pressure and therefore the maximum available traction.

**Figure 4. Test drive of the rover in 3m depth on a seaweed field.** *Credit: MOONWALK consortium, photo: Mathias Höckelmann, DFKI GmbH, 2015.*

The rover was already tested under realistic conditions in the Mediterranean Sea. Figure 4 shows one of the test-drives underwater. The rover proved its capability to traverse on the seafloor. And that the omnidirectional camera provides a good overview with sufficient details of the surroundings. The rover was also deployed from a boat to a depth of 11 meters. This depth and process is required for the simulations in Marseilles.

Not pictured here is the second part of the rover's system: the surface buoy. It was tested in the open sea too. Due to the mounting position of the antennas on the top of the buoys mast and 1 m above the sea surface, they were not hidden behind waves during the tests. This allowed a good connectivity over Wi-Fi to the buoy up to ranges of 50m. Below the antennas a capsize protection is mounted to the mast. During a deliberate capsize test, it showed, that it helps to prevent a full flip of the buoy. The tests showed also, that the visibility of the buoy is poor in direct sunlight. This may be an issue during the simulation, when third party boats can't see the buoy in advance.

**Figure 5. COMEX' GANDOLFI suit (1990 model) used for a lunar mission simulation at the sea bed offshore Marseilles (Frioul Islands);** *Photo courtesy A. Rosenfeld/COMEX*

### B. GANDOLFI-2 SUIT

GANDOLFI-2 is a new EVA training suit for lunar or Martian surface mission simulations in the frame of the Moonwalk project. The suit is design be used in the simulations scenarios of the Moonwalk campaigns underwater in offshore Marseilles and in the dessert-like area of Rio Tinto.

The novel suit is based on a previous EVA training suit (GANDOLFI) that was developed in the 1990ies at COMEX in cooperation with DASSAULT. The device has two major functionalities: i) it puts the subject in simulated microgravity (or reduced gravity) by floating elements (such as used for Neutral Buoyancy Training) and ii) it contains an exoskeleton that constraints the movements in order to simulate the movement constraints inside a real, pressurized spacesuit.

While the first GANDOLFI is based on the architecture of the Russian ORLAN suit, the new one is based on NASA's Z-1 spacesuit architecture in terms of morphology and movement constraints. Furthermore, the new suit can be used outside the water too (which is not possible with the previous version due to its dry-weight). Composite material for the exoskeleton and light weight design divided by three the weight of the new system compared to the existing one.

A further novelty in the new suit is the integration of a communication system that allows the astronaut to communicate with a Mission Control Center (in Brussels). It furthermore features gesture recognition sensors (IMU) to detect postures that might lead to falling down, detect falling down (incapacitated astronaut) and also to control the robotic companion of the astronaut by arm gestures.

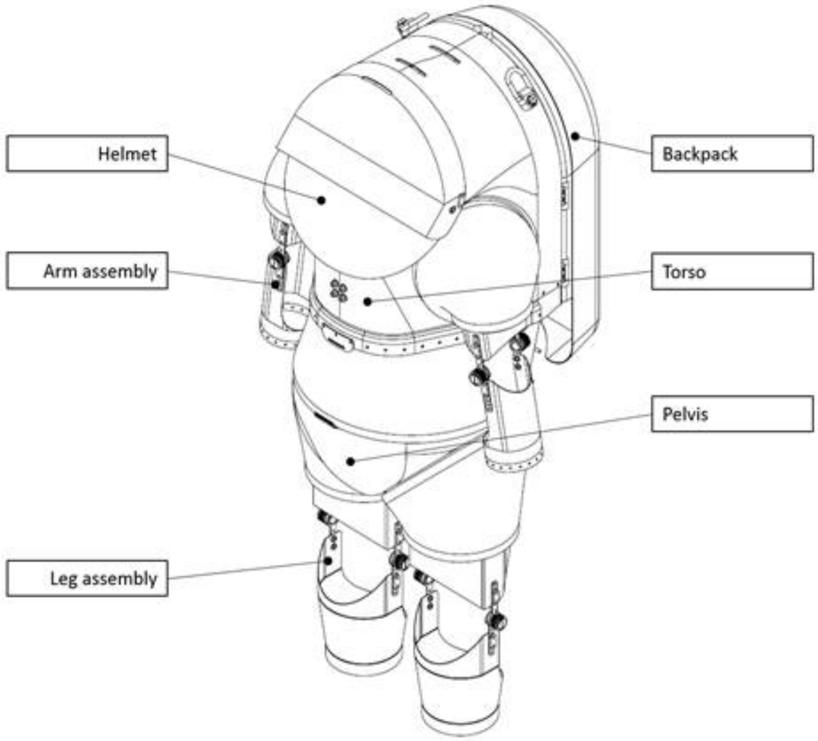



**Figure 6. Design of the exoskeleton of the EVA training suit. The exoskeleton will be covered by an oversuit, not shown;** *Credit: MOONWALK consortium, visualization: Comex, 2015.*

**Figure 7. First wet trials with parts of the novel exoskeleton of the EVA training suit.** *Credit: MOONWALK consortium, photo: Comex, 2015.*

### C. EVA Information System

The EVA Information System will consists of different Human Machine Interface (HMI) devices installed on the Moonwalk suit with the objective of comparatively testing new ways of improving the exchange of information of an Astronaut with Mission Control during EVAs and the situational awareness and autonomy of the Extravehicular Crew. The devices are displays with which the suited test subject can interact.

The HMI is designed to work with the constraints of a bulky space suit and will have features such as procedure viewing, media transfer, text message delivery, telemetry display, video and audio streaming delivery, voice loop system, robot control and communications during emergency situations.

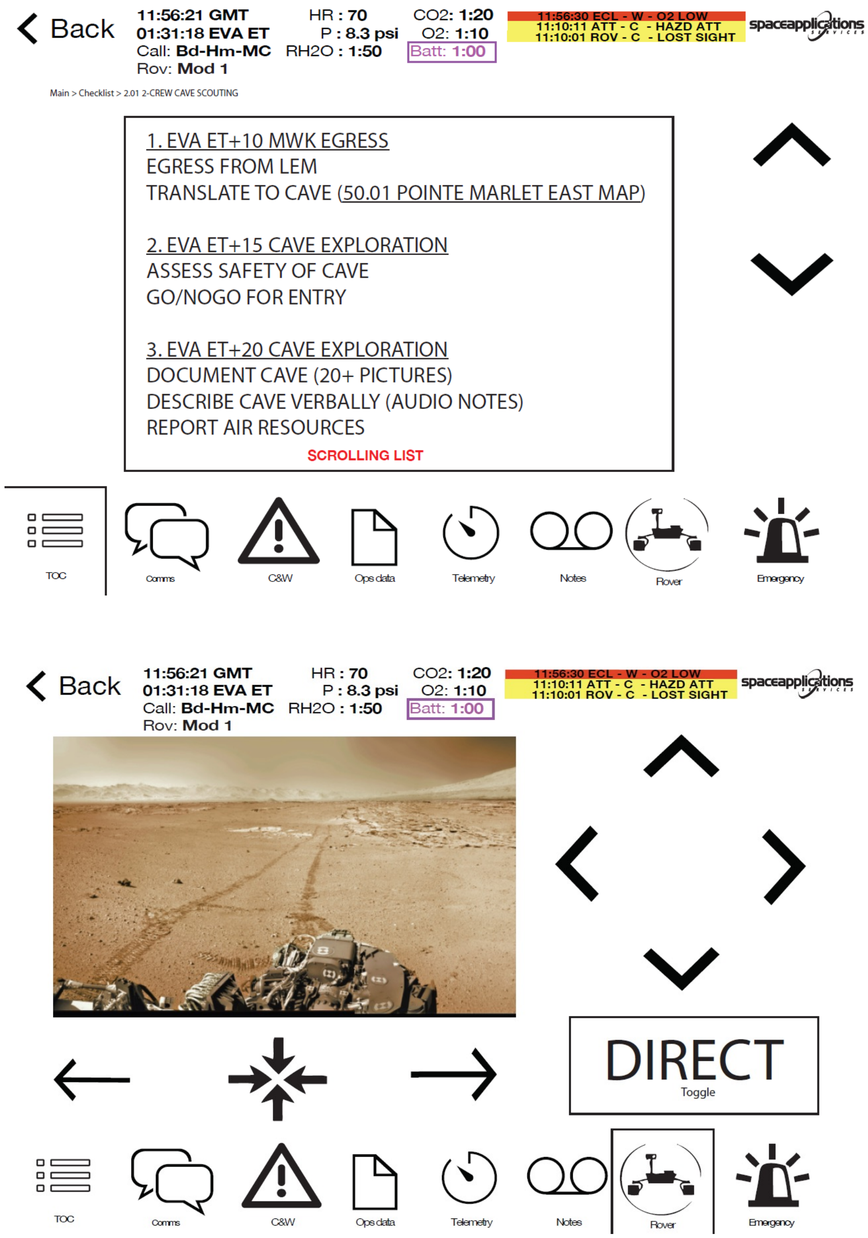



**Figure 8. Mock-up of the EVA Information System procedure viewing (top) and rover control (bottom).**
*Credit: MOONWALK consortium, visualization: Space Applications Services, 2015.*

The HMI for use in Earth-based Analogue simulations will also mimic various flight-like parameters like planetary mission communications delay and cautions/warnings of connected mock radiation sensors and life support systems.

The HMI will be fully ruggedized and waterproof for operations in water immersion partial gravity conditions, i.e. underwater in a natural setting. The communications system will log all the interactions among the EVA test subjects, and between the EVA test subjects and Mission Control.

## D. Mission Control Center

The Moonwalk Mission Control Center (MCC) is located in Brussels, Belgium, and operated by experienced flight controllers that will direct the simulated operations. Indications relevant to the experiments that need to be conveyed to, or obtained from the EVA test subjects will always go through the MCC. Nominally, three flight controllers, namely Flight Director (FLIGHT), Capsule Communicator (CAPCOM), and Robotics Officer (ROBO), will be present at the facility.

Flight controllers receive on-site information via, video feed, text and audio. The contents of this information includes; Cautions and Warnings, and Telemetry. This data is analysed in relation to mission procedures. Flight controllers can send operational data to the test subject, and control the Rover remotely.


**Figure 9. Visualization of the Mission Control Center in Brussels.** *Credit: MOONWALK consortium, visualization: Space Applications Services, 2015*

## E. Biomonitoring

Given the stressful and challenging environments experienced by astronauts, both during training and real missions, a new system of biomonitoring will be introduced to allow for the automated monitoring of the astronaut's health, in particular their physical and mental stress loads.

Personal health monitoring is becoming increasingly popular in the consumer world, and an increasing number of devices are becoming available to allow for individuals to monitor their activities, particularly Heart Rate. Devices such as the Apple Watch and the FitBit Charge HR offer sensors which can monitor and record the wearer's heart rate and activity. However, such equipment presents two broad problems:

a) How can physiological data be gathered in the difficult scenarios described above?
b) How should this data be analysed?

*1. Sensor Selection*

To tackle the first problem, an appropriate sensor needed to be selected which would work both in the subsea environment and in the desert-like Rio Tinto. A majority of sensors rely on common wireless technologies such as Bluetooth, which wouldn't work subsea owing to the signal attenuation. Therefore, a solution was identified with a sensor using a much lower frequency signal which would allow for heart rate information to be gathered from the Astronaut and relayed to the onboard Suit Computer Assembly for processing. Making the sensor components watertight would also have the added benefit of reducing the effects of dust, a significant challenge at Rio Tinto.

*2. Automated Data Analysis*

Gathering complex biological data requires analysis to add value. It is not practical to have a healthcare expert constantly analyzing a sensor feed to identify possible signs of stress.

Airbus Group Innovations has carried out research into user health and stress monitoring through the analysis of heart rate data, in particular, heart rate variability. Research has shown some potential for this to act as a metric indicating whether a user is under physical or cognitive loading (or a combination of both). A system is being developed where algorithmic analysis of the biological data will allow for an automated evaluation of the subject's stress levels. Therefore, mission commanders can better understand when astronauts are becoming physically or mentally stressed.

## V. Planned Evaluation

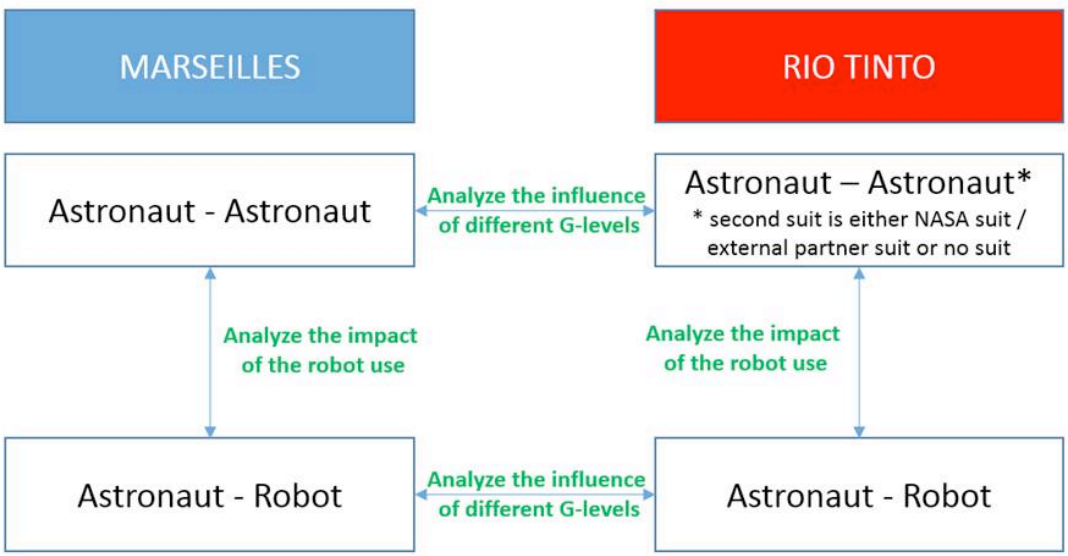



**Figure 10. The overall approach and focus for the comparative studies in project Moonwalk.** *Credit: M Moonwalk consortium, visualization: INTA, 2015.*

With the developed Moonwalk components and the dedicated mission scenarios two simulations are foreseen next year to test the hardware and software within integrated trials. A key aspect for validation is the evaluation of components and part in interaction.

The simulation missions' specific scenarios for human-robot collaboration will be evaluated and compared. Firstly, the same activities will be conducted in Rio Tinto and in Marseilles. Secondly, selected human-robot scenarios will be compared to astronaut-astronaut scenarios. Figure 10 show the overall approach and focus for the comparative studies. However, the main objective for the evaluation of Moonwalk is to collect meaningful data and perform relevant analysis that allows evaluation and comparison of astronaut-astronaut and astronaut-robot teams in terms of

a) Performance
b) Psychological impact of work in such teams

For the latter, focus will be kept on tasks and activities that will be performed in Moonwalk and how these are perceived by the executors. This can be done with mental workload techniques such as the commonly used NASA-Task Load Index (NASA TLX; Hart and Staveland 1988). The NASA TLX is a multi-dimensional rating tool that is used to derive an overall workload rating based upon a weighted average of six workload sub-scale ratings. The sub-scales are: mental demand, physical demand, temporal demand, effort, and performance and frustration level.

In addition to the mental workload analysis, it is necessary to gather information about other factors (physical, social, information flow, organizational factors, etc) that may affect performance and psychological impacts. This information will be collected by additional tools such as custom checklists, questionnaires or interviews conducted onsite or shortly after onsite operations (Stanton et. al 2005). The layout and content of these tools shall be defined as the project progresses, keeping in mind that the data collection should not interrupt the simulations.

For assessing team performance a combination of Behavioural Observation Scale (BOS) techniques (Baker 2005), supplemented by the use of metrics (Forrest et al. 2010), and timeline analysis (Kirwan and Ainsworth 1992) will be used. The starting point for these techniques is a hierarchical task analysis (HTA; Kirwan and Ainsworth 1992). HTA involves breaking down the task under analysis into a nested hierarchy of goals, operations and tasks. Then performance metrics for each task can be defined. The main focus will be on temporal metrics that may include such as time-to-completion, interaction time, neglect time, etc. The temporal metrics allow for comparison of subtasks across scenarios and are therefore very useful for comparison studies.

The collected data will be used to perform a timeline analysis of as-performed operations. Timeline analysis can represent team-based tasks and parallel activities; it can highlight problematic tasks or task sequences.

Additionally, workload analysis can be mapped directly onto the timeline graph. Apart from observation of temporal efficiency metrics, the performance analysis can include mission specific data such as area covered, situational awareness, communications and science accomplished. Such broad data can be collected either via questionnaires, interviews or reports and their inclusion in the analysis is important for providing information that relates to performance such as improvisational qualities, learning capabilities and human performance shaping factors.

## VI. Connecting Moonwalk to the international research community

As part of a project of this dimension a key aspect is the dissemination of the project's topics and the results. Therefore, the Moonwalk consortium seeks to reach out to the international research community and has released a call (Announcement of Opportunity - AO) for research proposals to be conducted in association with the simulation activities of the project which will take place in the first half of 2016. Researchers are invited to submit experiments focused on human and/or robotic exploration of the Moon and/or Mars. Experiments can profit from Moonwalk simulations and can take advantage of hardware and infrastructural resources Moonwalk offers access.

The analogue sites available through Moonwalk offer;

- an opportunity to study the behaviour of equipment, involving simultaneous usage of instruments by a human astronaut fitted with EVA suit
- a platform for testing various hardware, tools and techniques for scouting, imaging, monitoring, mapping, analysing and sampling the terrain
- the possibility to study iron-sulphate containing minerals (jarosite, hematite) and rocks as a model for their Martian counterparts
- the possibility to test EVA procedures and operations in reduced gravity conditions (neutral buoyancy)
- a platform for testing support teams in a remote location

The Moonwalk team also offers infrastructure to made available to researchers during both simulations. They include:

- access to Mission Control Center, Brussels, Belgium.
- access to the communications loops.
- access to live telemetry at a Remote Science Center in the premises of the PI or at MCC.

All proposals will be reviewed by a process of peer-review and will be assessed for quality of proposed research and feasibility. All research must be self-funded, however Moonwalk will provide the scientific and logistics infrastructure if possible.

Preference will be given to experiments that;

- respond to the current need of human space exploration as outlined in ESA, NASA or other pertinent roadmaps; (http://www.globalspaceexploration.org/wordpress/wp-content/uploads/2013/10/GER_2013.pdf)
- exploit the environmental, topological, geochemical, biological and/or partial gravity (analogue) aspects of the sites
- require EVA crewmember(s) to interact with equipment, tools, technology, or to carry out procedures, etc
- exploit the full chain of communication between Mission Control and EVA crew in a purposeful manner
- are in sync with ongoing research at the particular sites of subsea Marseilles and/or Rio Tinto

## VII. Conclusion

A considerable number of simulations have been performed in the analogue field in the last 10 years since simulation research has been recognised as an important tool for future exploration missions such as the NASA D-RATS or NEEMO missions. ESA has been issuing calls in this direction, either to select and describe analogue mission sites world-wide (CAFE; L. Preston, 2011) or to identify needs and concepts for Analogues for Preparing Robotic and Human Exploration on the Moon (LUNA; Space Applications Services et. al, 2015). Most recently ESA has issued a call for proposals for LUnar scenario Concept validation and Demonstration (LUCID; ESA, 2015). Further, in the EU's latest framework programme the tendency is towards expanding analogue research and simulation.

Moonwalk is set into this context and adds novelty in three different aspects:

1. *Astronaut and small rover collaboration as part of surface exploration*
2. *Innovative concepts of a small rover and an analogue astronaut suit that can be used in under-water and on-land simulations*
3. *Human-controlled interaction with a rover through gesture control*

Moonwalk is planned as a complex set of key components such as

- technology development (Asguard rover, simulation suit, human-machine interfaces)
- field trials and mission simulation
- scenario development and analysis of the above
- collaboration with international researchers
- dissemination

In this way Moonwalk contributes to the advancement and preparation of future exploration on extra-terrestrial planets.

## Appendix

### A. Note on the Announcement of Opportunity

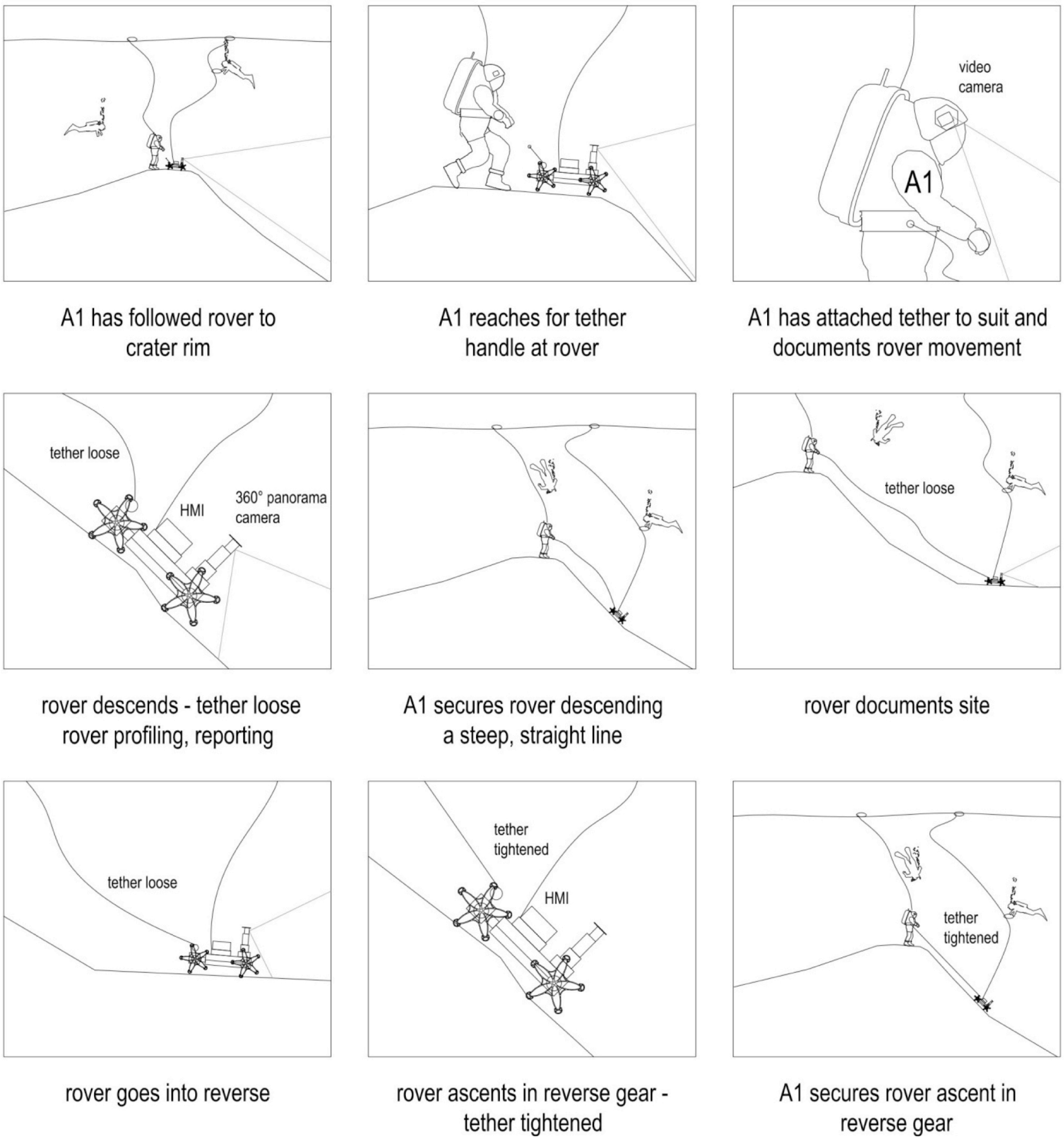
The deadline for experiment proposal submissions is 31.October 2015. The announcement of the selected proposals will be released on 7 December 2015. More information can be retrieved from www.projectMoonwalk.net/participate

### B. Storyboards of the mission simulation scenarios

For further information, please see the Moonwalk's scenarios which have been selected as baseline for the mission simulations.

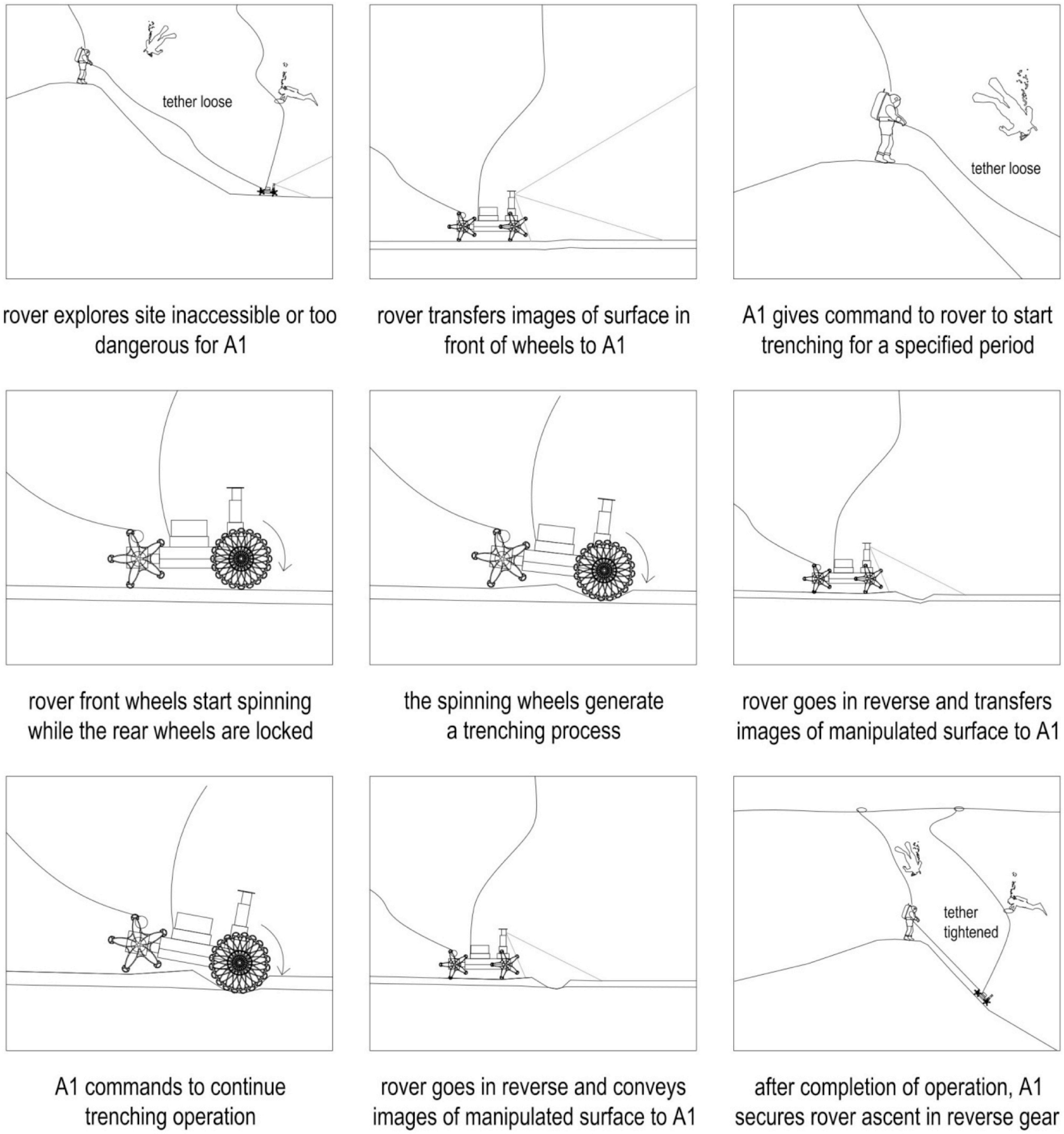
1. *Subsea Marseilles Lunar Analogue site in France*

## Exploration and scouting of a crater including astronaut and a tethered rover



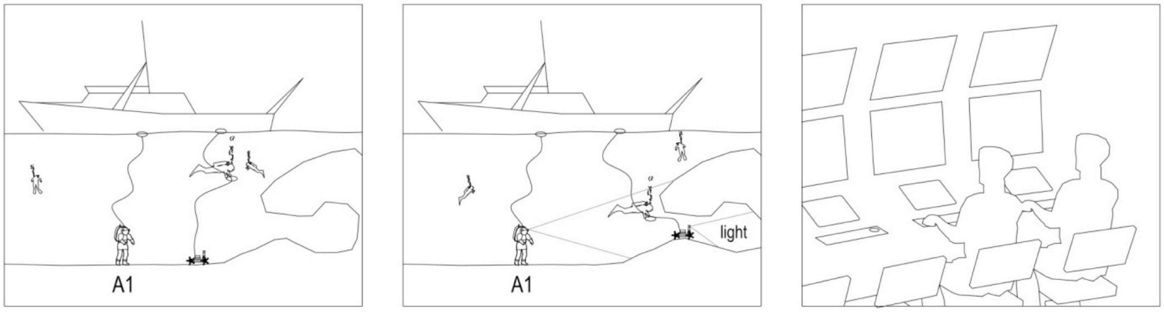

*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Astronaut investigates samples while the rover trenches soil




*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

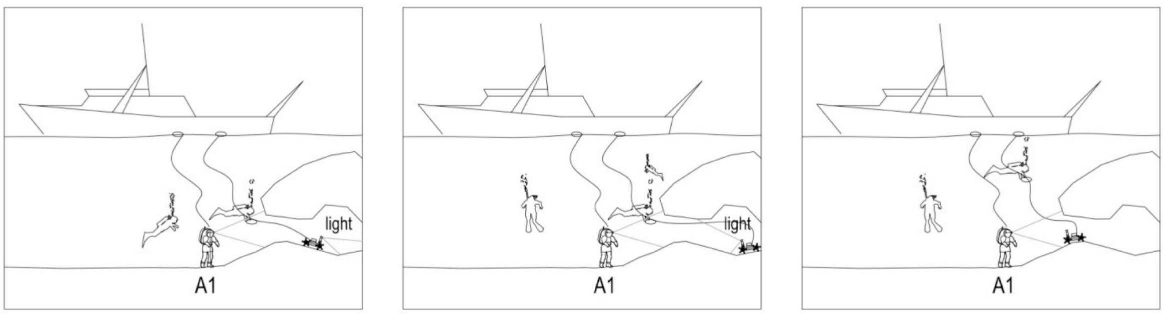
## Exploration and scouting of a cave including astronaut and rover




communication A1 - rover, direct command: explore cave site

rover turns on light at cave entrance to perform exploration with camera

communication CC - A1 / rover, A1 or CC gives ok to enter cave



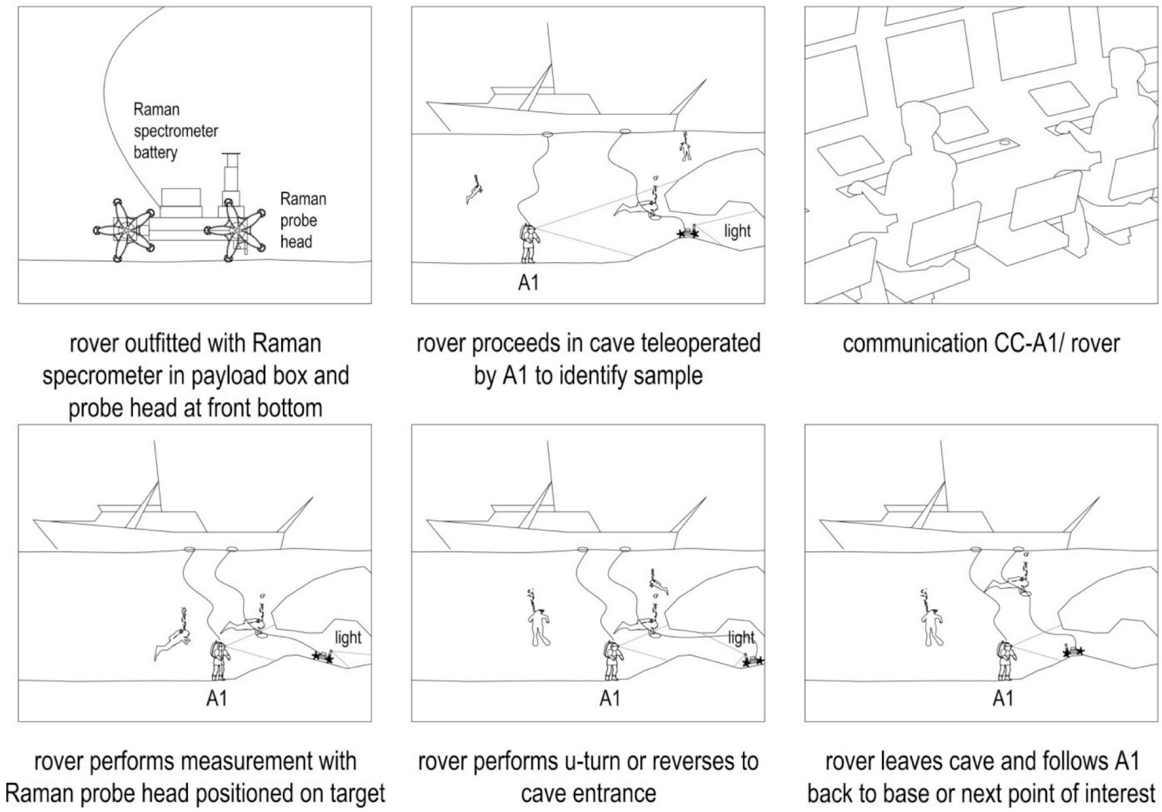

rover proceeds teleoperated into cave

rover performs u-turn or reverses to cave entrance

rover leaves cave and follows A1 back to base or next point of interest

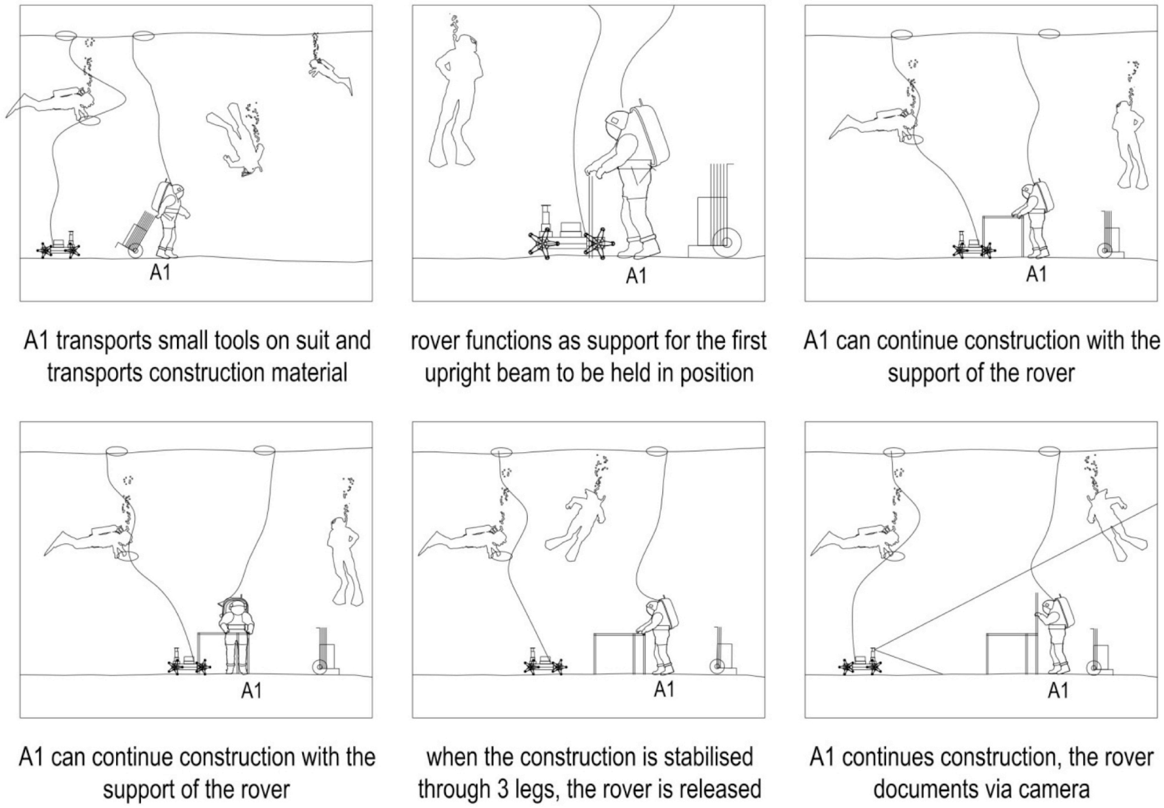
*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Astronaut receives information from the rover while the rover collects information with a Raman spectrometer in a cave



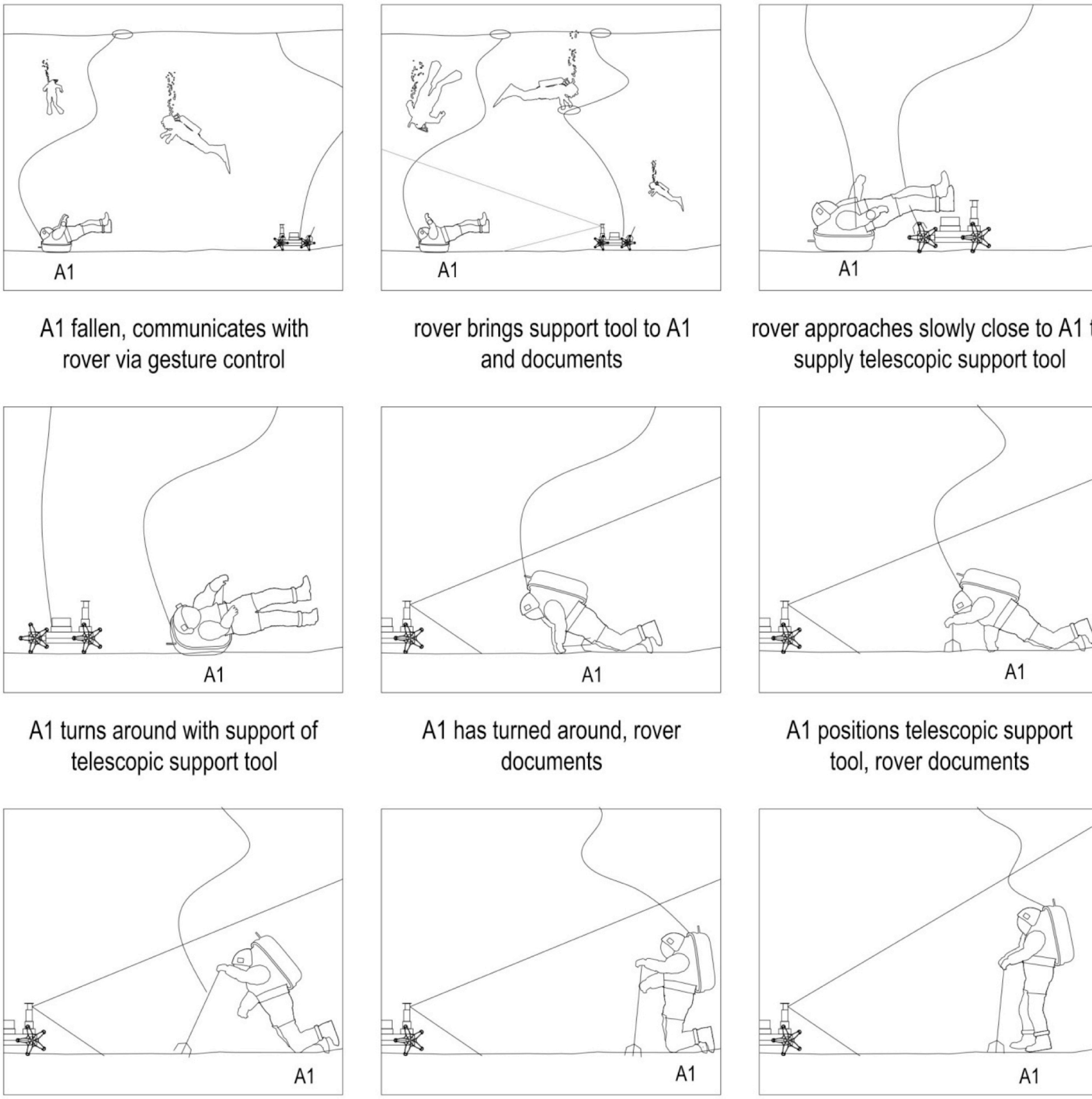

*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Astronaut and rover construct a tool shed together




*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

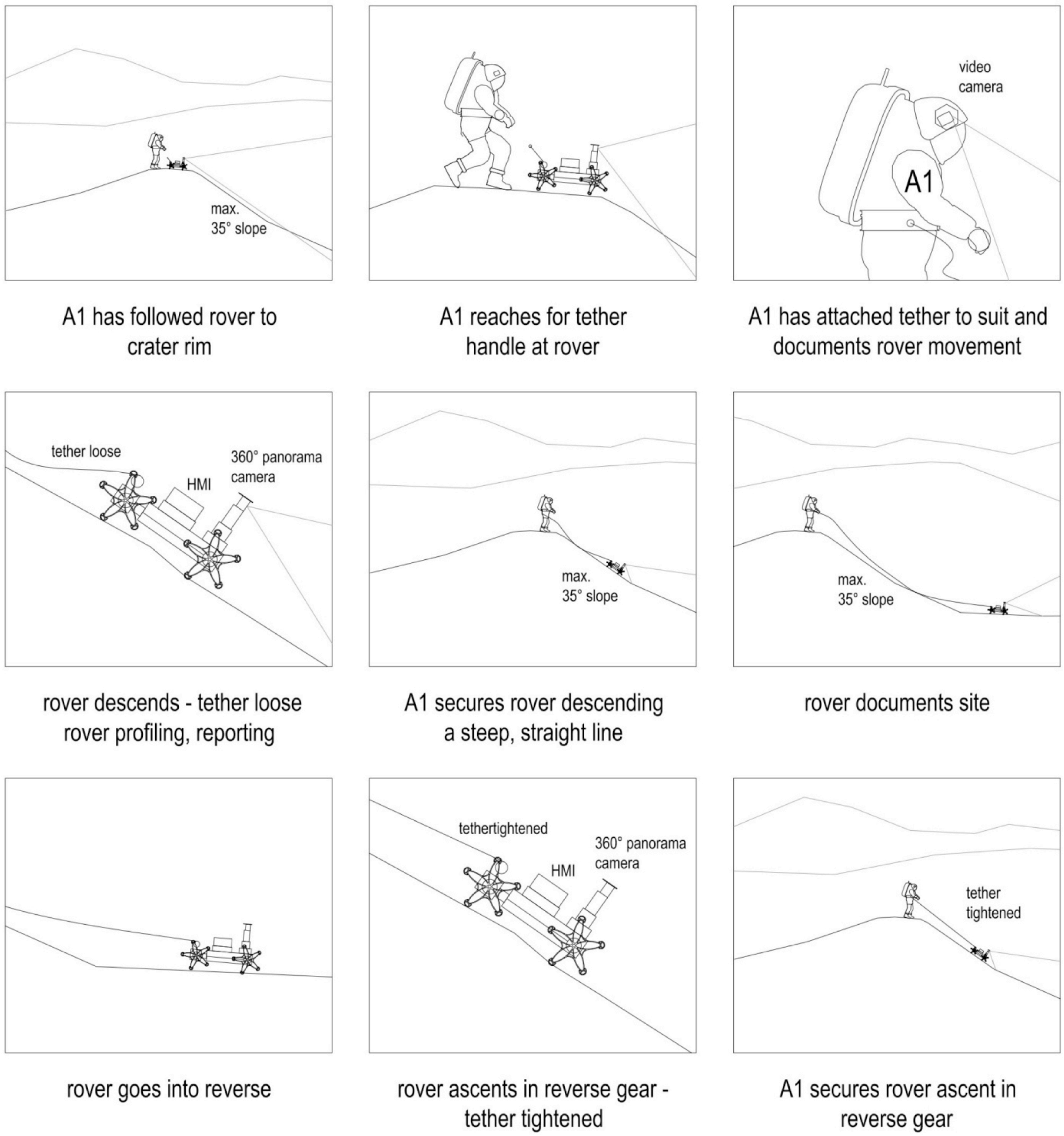
## Emergency scenario; Rover helps the fallen astronaut to get up again by bringing a tool to the astronaut




*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

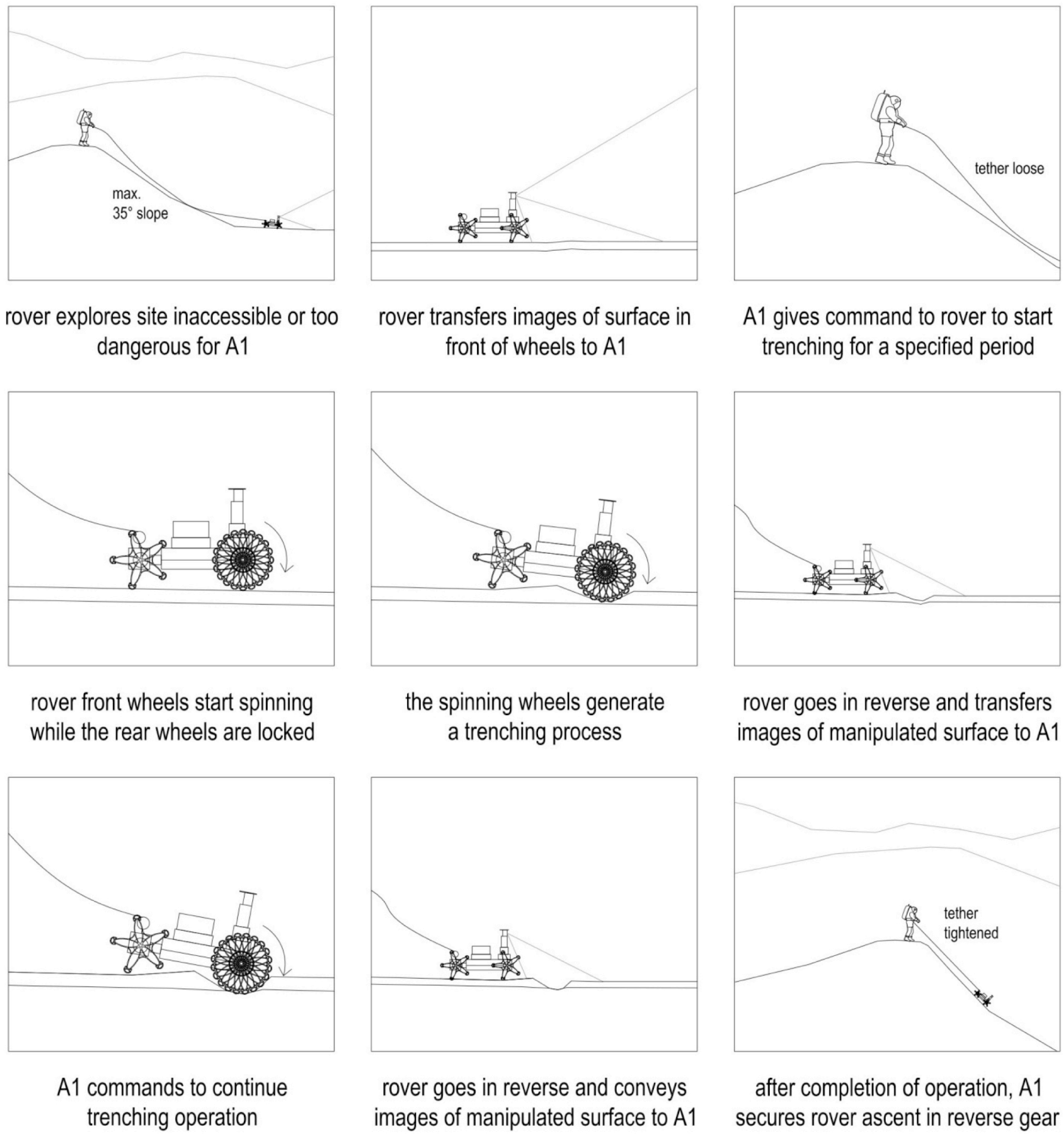
2. *Rio Tinto Mars Analogue site in Spain*

## Exploration and scouting of a crater including astronaut and a tethered rover



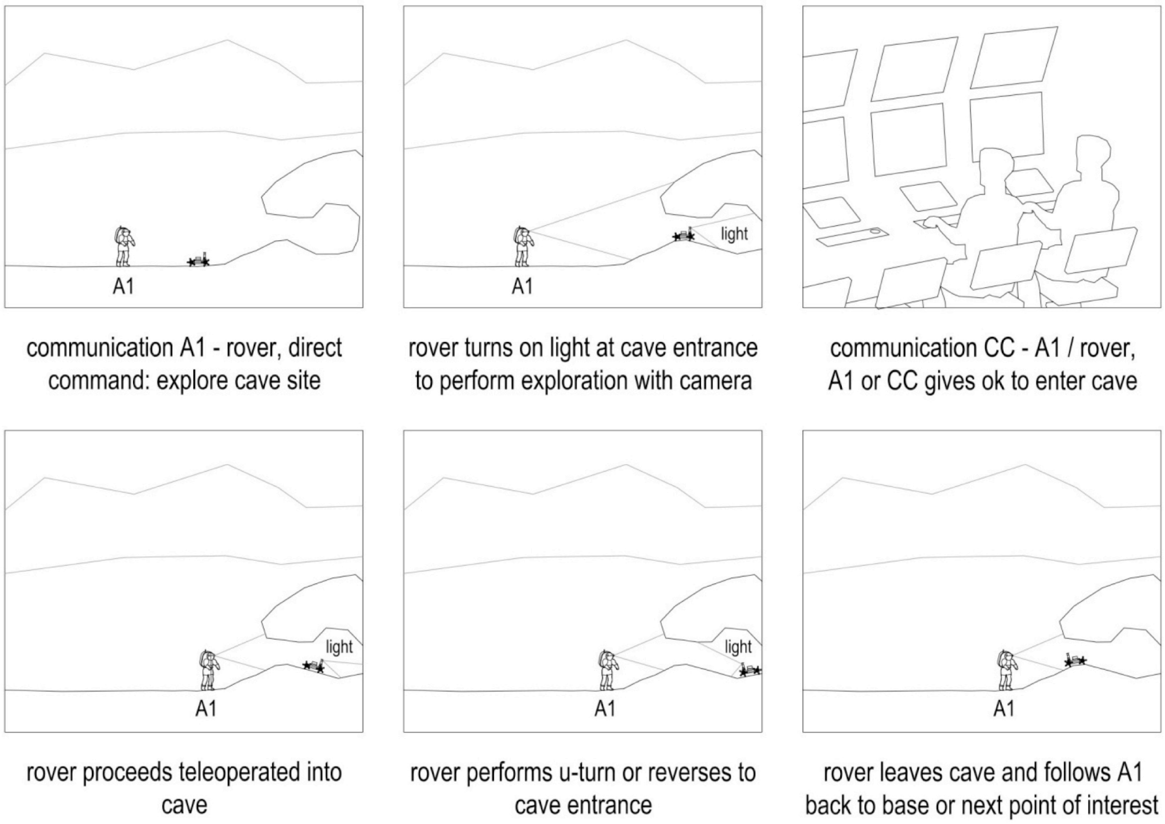

*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Astronaut investigates samples while the rover trenches soil



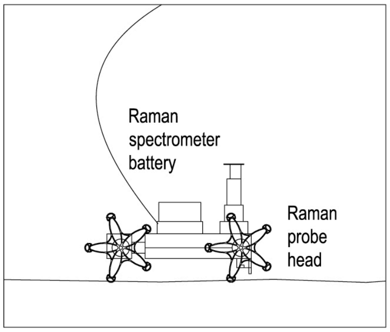

*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Exploration and scouting of a cave including astronaut and rover

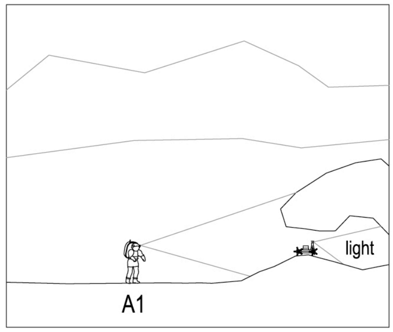



*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

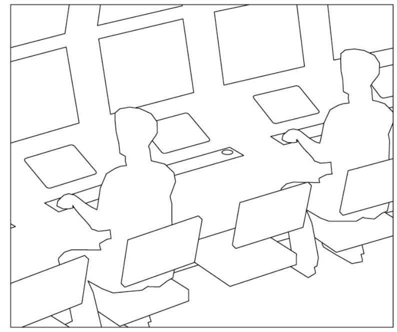
## Astronaut receives information from the rover while the rover collects information with a Raman spectrometer in a cave



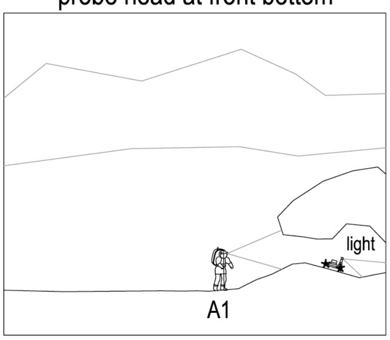

rover outfitted with Raman specrometer in payload box and probe head at front bottom



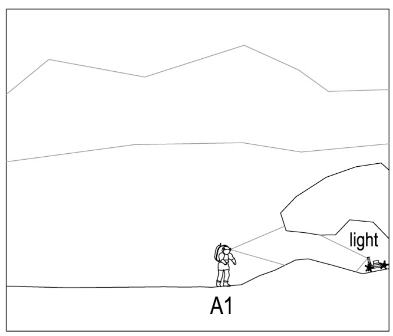

rover proceeds in cave teleoperated by A1 to identify sample



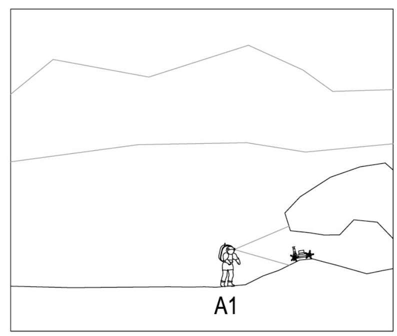
communication CC-A1/ rover




rover performs measurement with Raman probe head positioned on target



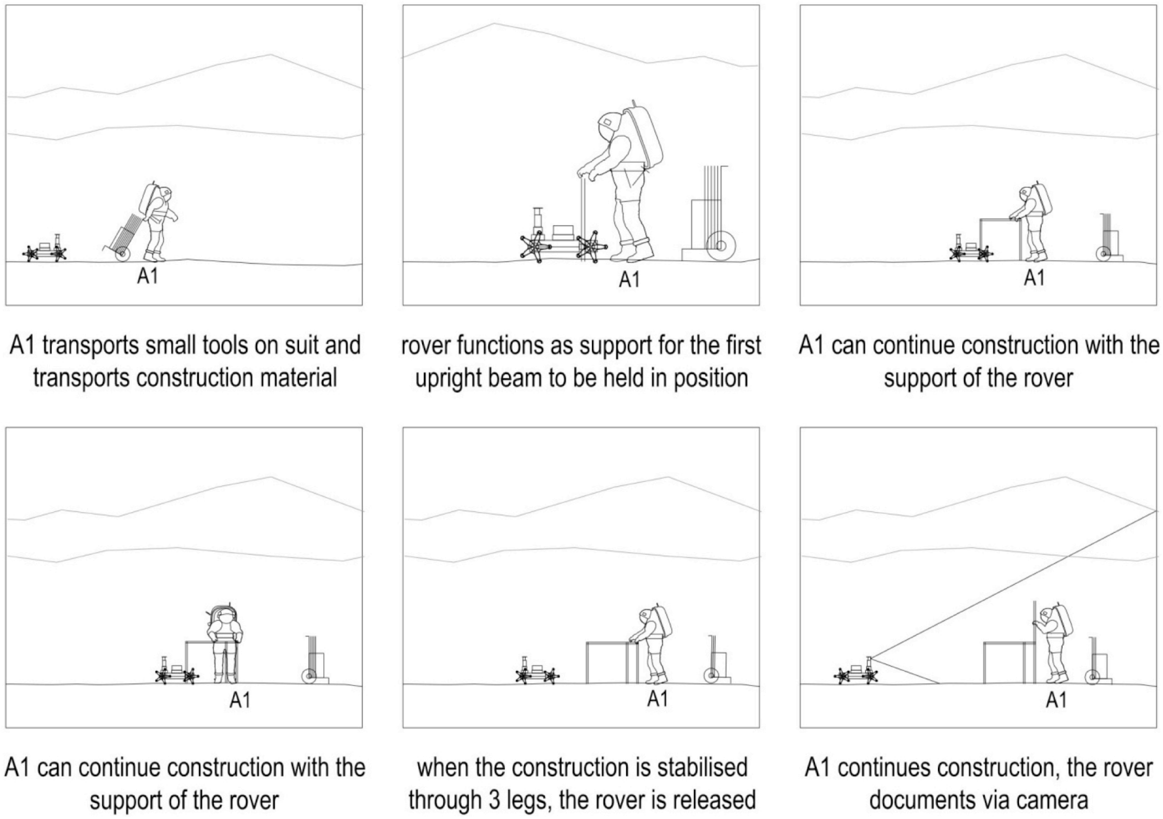

rover performs u-turn or reverses to cave entrance




rover leaves cave and follows A1 back to base or next point of interest

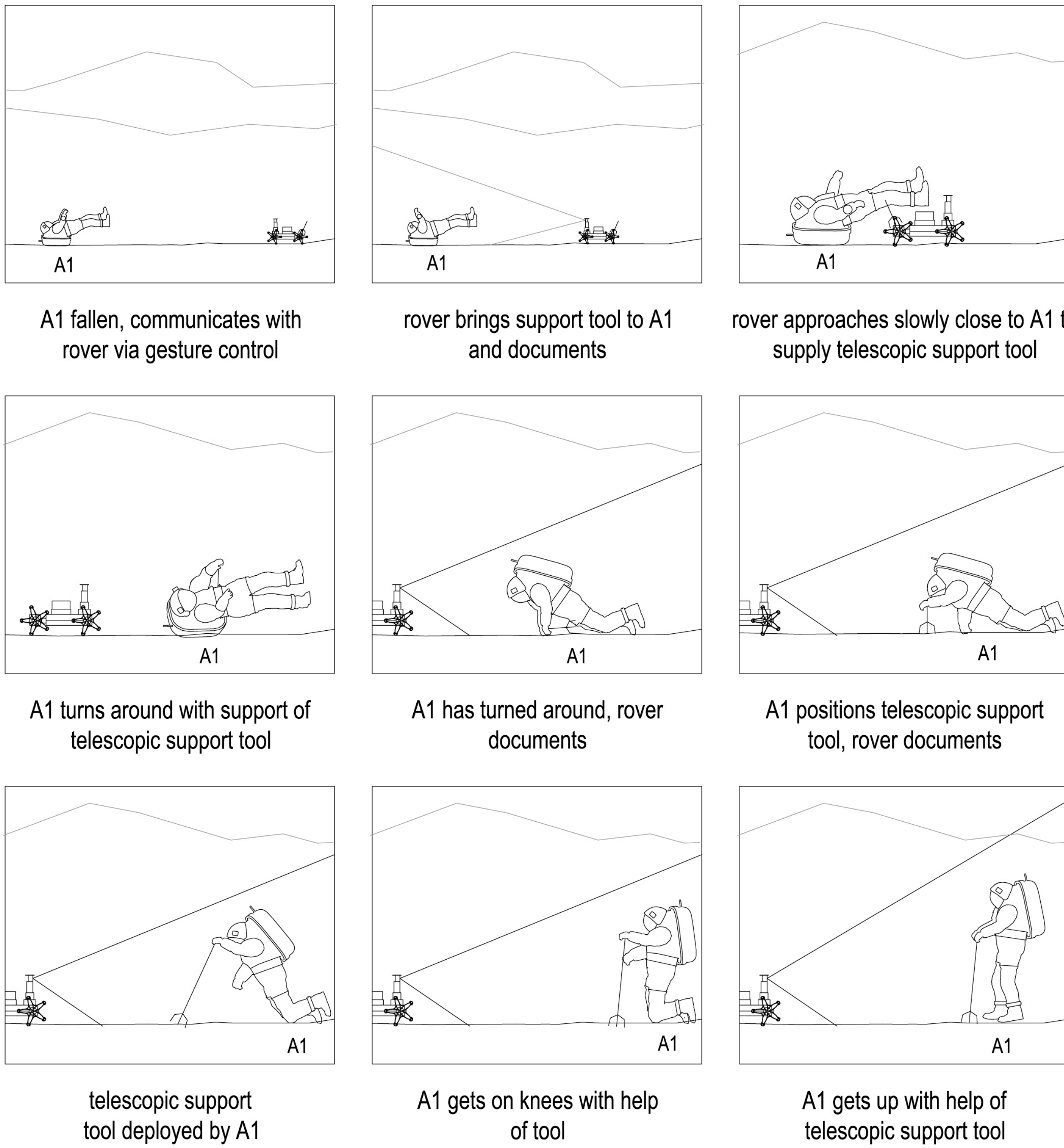
*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

## Astronaut and rover construct a tool shed together




*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

**Emergency scenario; Rover helps the fallen astronaut to get up again by bringing a tool to the astronaut**




*Credit: MOONWALK consortium, visualization: LIQUIFER Systems Group, 2014.*

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