Summary Outcome and Recommendations
Workshop on Landing Sites for Exploration Missions
Leiden/Noordwijk 17–21 January 2011

EXECUTIVE SUMMARY

The first European Workshop on Landing Sites for Exploration Missions took place at the Lorentz Centre, in Leiden (NL) on 17–21 January 2011. The workshop was organised in the framework of a Europlanet JRA1 (Support to Future Missions) grant. It gathered more than sixty participants from the space science and engineering communities in Europe, the United States, and Asia. The workshops programme combined a series of lectures presenting different perspectives on landing sites with hands-on sessions involving small, interdisciplinary teams focussing on specific mission scenarios. The goal of the workshop was to bring together the international landing site community to start preparing for landing site selection and characterisation activities serving missions having a European component. The week was concluded with a conference at ESTEC, focussing on the international programmatic context of robotic exploration missions.

This report presents the workshop's outcome, recommendations, and detailed results of the various mission scenarios that were studied: three Mars mission scenarios (2016 Entry Descent and Lander Demonstrator, 2018 Dual Rover Mission, and Mars Sample Return); a mission to a small solar system body, such as Phobos or an asteroid; and a Google Lunar X-prize mission to consider landing site selection approaches for commercial missions).

INTRODUCTION

Europe is currently in the process of defining solar system exploration activities through programmes of the European Space Agency (ESA) and the European Union (EU).

Scientific analysis constitutes an essential component of robotic planetary missions. Scientific analysis, when applied to landing site selection and characterisation, contributes to enabling two critical success factors for surface robotic missions: 1) Entry, descent, and landing safety, through an iterative process with project engineering; and 2) Access to a scientifically interesting terrain where the mission may achieve its exploration and science goals.

Landing site selection and characterisation entails the processing and interpretation of diverse remote sensing data sets. Its objective is to derive those surface properties that are essential to demonstrate that a location is appropriate to accomplish the mission's scientific objectives and compatible with the landing site engineering constraints imposed by the landing system and the mission's surface operation capabilities (e.g. rover locomotion). On the basis of integrated mineralogical (spectroscopy) and morphological (visual and topographic) analyses, science teams can assess the geological environment and science interest of candidate landing sites, the most relevant of which can be proposed for further consideration. Proposed sites are characterised in ever-greater detail (usually by requesting targeted high-resolution observations by instruments on-board currently active orbiters) to verify that they are scientifically interesting and safe. Additionally, these data are also required in support of rover surface operations. For example, to aid in navigating to particular locations where spectral signatures for aqueous or hydrothermal processes have been preserved.

GENERAL OUTCOME AND RECOMMENDATIONS

Landing site characterisation is critical for mission success. Missions with a surface component (probes, landers, rovers) require a careful analysis of the scientific, physical, and environment properties of potential landing sites. Geological, compositional, and morphological characterisation, as well as an evaluation of slopes, rock distribution, thermal inertia, and atmospheric conditions at the time of lander arrival, constitute key steps to ensure a match between the spacecraft system and the candidate landing site under consideration.

For an effective and successful landing site selection process, it is essential to ensure continuous interaction between project teams and the science community proposing and characterising landing sites. The landing site selection work is, by its very nature, a long, iterative process involving targeted observations, careful data analysis, and frequent interaction with the project team involved in spacecraft design. Understanding and coordinating the engineering and science components that this work entails are key elements to ensuring success.

Recommendation 1

Maintain and further develop a coordinated forum through which scientists and engineers can interact and communicate on the topics of future exploration missions (design, landing sites, operational aspects). Face-to-face workshops are essential in this process, as well as a continuum of information exchange and discussion via a web-based platform such as PlanetaryGIS.org. This will facilitate the convergence of the currently fragmented knowledge and expertise present in the European planetary community, and will serve as a platform to coordinate international efforts in this field.

Landing site analysis is essential at an early stage of any landed mission's design and development. Planetary surface analysis is complex and requires the integration of data from different instruments and missions in a single geographic framework. The derivation of relevant surface attributes (e.g. topography, mineralogical and chemical composition) from scientific data available in publicly accessible planetary science archives (PSA, PDS) is non-trivial, time consuming, and requires unique scientific expertise typically available in the planetary science and terrestrial geosciences community. The results of scientific terrain analysis may have implications for mission design and technical trade-offs during the design and development phases.

Recommendation 2

Landing site selection activities for the Mars 2018 mission need to be commenced as soon as possible because currently active orbiter missions (MRO, Mars Express) providing critical landing site data are already in their extended missions and may have a limited remaining lifetime. There are no follow-up missions planned with the complement of instruments currently available on MRO and Mars Express.

Generally, the most relevant terrains for surface missions with specific science and exploration goals are those having a relatively rugged topography, providing access to multiple geological units. Such terrains allow sampling of a variety of rock types covering an extensive geologic period. These characteristics will often not be compatible with safest landing areas, which are typically uniform and flat. Two means of reconciling this conflict are: a) to combine **high precision landing with hazard avoidance**, and b) to have **rovers with increased mobility**, enabling consideration of so called "go-to sites", where the primary sites of scientific interest may lie outside the landing ellipse.

> **Recommendation 3**
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> Precision landing and hazard avoidance are critical technologies, which have the potential to greatly enhance the science and exploration return of missions. These technologies provide the opportunity to land in terrains with high science and exploration interest that would be otherwise inaccessible.

For Europe, landing site selection is a new activity. The selection process needs to be defined and developed. NASA has several decades of experience in the successful execution of Moon and Mars surface missions. Tailored to the US science community and NASA programmatic and funding framework, landing site selection is now a well-established and refined process. Members of the European scientific community have actively contributed to NASA-led landing site selection efforts, such as for the 2003 MER and 2011 MSL missions. As ESA and NASA progress in the consolidation of a cooperative Mars programme, landing site selection activities for joint missions must be integrated into an internationally coordinated process. For European-led missions, a landing site selection process, adapted to the European science and programmatic environment, must be established.

> **Recommendation 4**
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> That all landing site selection processes in the framework of ESA-NASA cooperative programmes be conducted in a joint manner.

A European programme is needed for funding scientific studies supporting characterisation and mapping of planetary surfaces. In the European context, the engineering portion of the landing site selection work is funded by ESA as part of project work. Funding for the scientific analysis of spacecraft data in support of landing site selection activities, on the other hand, is not yet coordinated at European level, but fragmented, and with different levels of interest depending on national funding agency priority.

Recommendation 5

Implement a funded European data analysis and dissemination programme to exploit ESA mission data in preparation for Mars, lunar and small bodies missions. Both long-term strategic and shorter-term mission dependent activities should be covered:

- Strategic activities that underpin landing site selection include planetary cartography and geodesy, geological mapping, mapping standardisation, and dissemination of higher-level geographic information products. This is analogous to the USGS Astrogeology activities [http://astrogeology.usgs.gov/], and should also take full advantage of the terrestrial mapping and information management workflows and technologies developed by Europe's geological surveys.

- A data utilisation programme to allow scientists to do the preparatory research before proposals for landing sites can be developed in support of ESA missions and other international exploration missions.

- Mission-specific activities include procurement by ESA-NASA of specific data sets or analysis of data for which the knowledge resides in the science community (e.g. atmospheric models, digital terrain models, surface composition maps, as is done in the NASA Critical Data Products (CDP) Program [http://mepag.jpl.nasa.gov/cdp/index.html] for Mars data). Based on the NASA experience, it is recommended that such data analysis programmes be managed in a project independent, open, and competitive manner appropriate to the acquisition of scientific information (open call for proposals, review process, and open dissemination of results), possibly as part of a landing site selection process.

Acknowledgements

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ANNEX 1: OUTCOME FROM HANDS-ON SCENARIO SESSIONS

Scenario #1: 2016 ExoMars Entry, Descent and Landing Demonstrator (EDM)
The Exomars programme will demonstrate key flight and *in-situ* enabling technologies in support of the European ambitions for future exploration missions. The 2016 mission is led by ESA and consists of an Orbiter Module (OM) that will carry the Entry, Descent and Landing Demonstrator Module (EDM). The EDM will be released in its entry trajectory to a previously identified landing site, in Meridiani Planum. The choice of such landing site was primarily driven by safety constraints, availability of extensive datasets over the area, and the already successful landing of NASA's Spirit rover, which has provided ground truth complementing the orbital data gathered by multiple missions.

The 2016 Scenario Team (coordinators: Leila Lorenzoni, Angelo Rossi; members and support: Alessandra Marcer, Stefano Portigliotti, Felipe Gomez, Hans Krüger, Valentina Masarotto, Paulina Reizi, Takehiko Satoh, and Matt Golombek) qualitatively analysed the EDM's Landing Site Engineering Constraints (LSEC) in combination with global datasets (mainly thermal inertia, topography and its derived parameters). In this scenario the team followed the ExoMars 2016 project practices for identifying an alternative landing site in the 25–30 N latitudinal range, compliant with the mission's LSEC. LSEC include topography below ≤ –1300 m MOLA (included in the global entry corridors), a landing ellipse of 100 km x 30 km with an azimuth of 120° to 160°, global entry corridors, slopes at various length scales, rock abundance, albedo constraints, and thermal inertia.
Considerations regarding global Viking IRTM-derived Rock Abundance (RA) and Mars Global Surveyor (MGS) TES-derived Thermal Inertia (TI) ruled out large portions of the LSEC-derived geographic windows for landing. This resulted in only two shortlisted macro-areas in the northern hemisphere: one in Arabia Terra and the other in the Elysium-Isidis Planitia (Fig. 1).

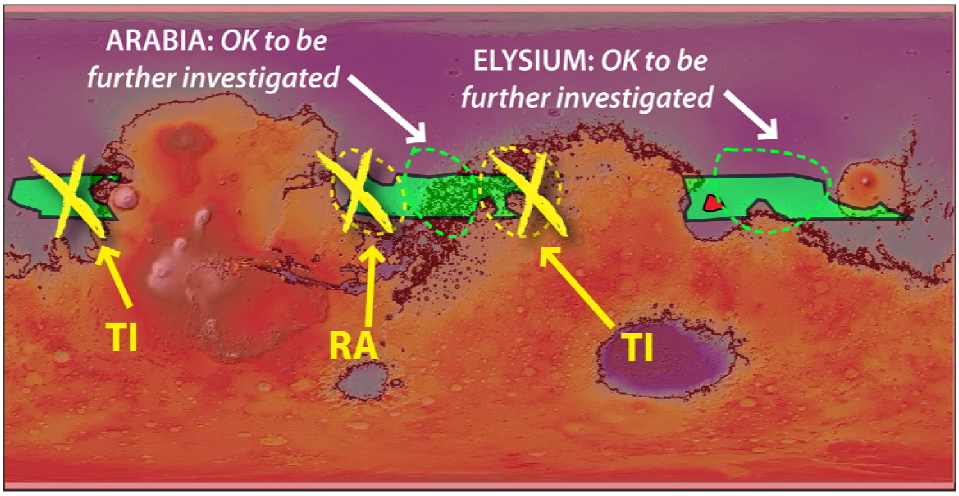

Figure 1: Envelopes (green dashed outline) in which the 2016 EDM Scenario exercise looked for potential landing ellipses in the 25°-30° N latitude range. At this scale single ellipses cannot be visualised. The mission's LSEC were used to identify "go" areas (semitransparent solid green polygons), parts of which were later partially or totally rejected on the basis of Thermal Inertia (TI) and Rock Abundance (RA) values.

The 2016 ExoMars EDM Scenario goals were partially achieved, showing that:

- "No Go" areas are easily identifiable with a qualitative approach.
- Non-quantitative dataset representation and visualization can be helpful during discussion.
- Definitive assessment can be performed only with high-quality, high-resolution, properly calibrated, mapped and co-registered data, to be evaluated by EDL performance analysts.

Scenario #2: ExoMars Rover on 2018 Dual Rover Mission

The 2018 Dual Rover Mission is part of the Joint Mars Exploration Programme (JMEP), currently in the process of being implemented by ESA and NASA. The 2018 mission will land ESA's ExoMars rover and a NASA rover (MAX-C). The current scenario assumes that the two rovers will be delivered to the exact same location, most likely accommodated on a landing platform, lowered to the surface using the Skycrane system developed for NASA's 2011 MSL mission. The size of the landing ellipse is approximately 20 x 20 km.

The main goal of the ExoMars rover mission is to search for traces of past or present life either as structural biosignatures observable at the macro-microscopic scale and/or organo-geochemical signatures in subsurface samples (obtained with a drill at depths from 0 to 2 m) that have been protected from surface oxidation and radiation degradation. The NASA rover is considered the first step of an international Mars Sample Return (MSR) effort. It will include instruments on a robotic arm for characterising surface rocks and soils, and a rock corer to obtain small samples that can be stored in a cache system. The cache would be left on the surface for a future MSR mission to collect and return to Earth.

The possibility of potential collaborative activities between the two rovers (the "2-Rover International Science Analysis Group" (2R-iSAG)1, has an important impact on the choice of landing site.

Main Findings

Besides the individual, but complementary, science objectives of the two rovers, two further rover properties have an important impact on landing site specifications: nominal mission duration and traverse requirements. At present the ExoMars rover is being designed for a 180-sol nominal mission. During this period, the rover is assumed to cover approximately 2 km, as it will spend many sols at each drilling location. The NASA rover has notional lifetime requirements of one Martian year (668 sols) and up to 20 km in traverse range.

Given these requirements, the group derived the following criteria related to the landing site selection for the 2018 Dual Rover Mission:

1. The landing site priority is for an area containing outcrops and/or subsurface materials having a high potential for hosting well-preserved evidence of past life. However, certain scenarios could be envisaged in which present life could occur in subsurface materials (for example, in the cryosphere).
2. The 2018 mission's landing site must contain multiple instances of rocky outcrops that can be demonstrated to have been in contact with liquid water for extended periods, allowing water-related chemistry processes to take place. This means stable water hosting environments in which life could have appeared and/or that could have supported life. Such environments can be identified from orbit by the presence of hydrated minerals, related for example to surface aqueous alteration, including sediments, or to hydrothermal alteration associated with volcanism or impacts.
3. Ancient, Noachian and early Hesperian, outcrops are preferred, as they have a greater chance to have recorded the presence of long-lived bodies of liquid water.

[1] Grant, J., Westall, F., and the MEPAG 2R-iSAG team (2010). Two rovers to the same site on Mars, 2018: Possibilities for Cooperative Science, 46 pp., posted July 21, 2010, by the Mars Exploration Program Analysis Group (MEPAG) at http://mepag.jpl.nasa.gov/reports/

4. Recently exhumed terrains are preferred to avoid long-term exposure of, especially, the organic components to the destructive oxidative and radiative conditions present at the surface over the last 3 billion years.
5. Outcrops in the landing site must show good potential for the preservation of morphological and organic biosignatures. Though isotopic biosignatures are also interesting, the rover payloads are not equipped to perform detailed isotopic analysis.
6. The current engineering criteria for the landing and rover mobility require a landing site:
   - At a maximum altitude of –1 km MOLA;
   - At a latitude between 5 °S and 25 °N (going outside these limits would require substantial modifications to the ExoMars rover);
   - At a site with a thermal inertia > 100 TIU (for good radar performance);
   - Where the hardness of the targeted rocks are within the capabilities of drilling for ExoMars (i.e. softer than basalt);
   - With slopes and rock density as limited as possible (the accepted values will depend on the landing solution and the capabilities of the rovers that are still to be determined);
7. The highest priority science targets must be within the landing ellipse. This is due to the limited traverse distance (2 km) that the ExoMars can achieve during its nominal mission lifetime (180 sols). "Go to" sites must be avoided (Fig.2).

Since the landing system of the 2018 Dual Rover Mission is based on that of MSL, and because both rover missions' science goals translate into similar landing site desired characteristics, the group looked at the landing sites short listed for the MSL mission that lie within the 2018 mission's latitude constraints. Only two can meet the science criteria, especially in the perspective of MSR landing at the same site. Only one, Mawrth Vallis, satisfies the non "go to" site nature of the landing site. Most other scientifically interesting targets are hazardous for a safe landing on some part of the ellipse. Adding a hazard avoidance capability to the landing system would give broader possibilities, allowing consideration of sites with a mixed terrain —safe and unsafe— nature.

A critical outcome of this workshop was the realisation that discussions in Europe about possible landing sites must begin as soon as possible, especially when interactions between two rovers and future missions (MSR) are to be considered. There is a significant pool of experts in Europe with the competences to contribute to the landing site selection procedure and to study the impacts of the landing site choice on mission planning and vice-versa. They should be solicited now to form the initial group to explore these issues.

Scenario #3: Mars Sample Return with samples from 2018 mission

NASA and ESA have long recognised the value of returning carefully selected samples from the Martian surface to laboratories on Earth for addressing key scientific questions requiring sophisticated sample processing and analysis techniques. However, neither agency expects to have the resources to accomplish this objective alone. As a logical next step, considering the good history of collaboration and the synergy in their programme's objectives, ESA and NASA have taken steps to form an even stronger partnership in robotic Mars exploration. This joint programme would span several launch opportunities, include rovers and orbiters to conduct high-priority investigations, and aim at returning samples from Mars in the 2020s.

Forty years on, the analysis of the samples brought back from the Moon by the Apollo astronauts still results in important new discoveries. Samples brought back from Mars may represent the only way to confirm traces of past life on Mars with a good level of confidence. The scientific goals of MSR include exobiology, targeting aqueous sediments or hydrothermally altered rocks, planetary dynamic evolution, and targeting volcanic and other igneous rocks[2]. To fulfil this broad range of sampling goals, the landing site should be as diverse as possible within the range of the rover that will collect the samples. However, a clear primary aim is to collect material that may have preserved evidence for past or present life. In the current scenario, MSR will bring back samples cached by the 2018 MAX-C rover. For this reason, MSR landing site selection considerations are linked to those of the 2018 Dual Rover Mission (MAX-C and ExoMars)[1]. The 2018 rovers need to be directed at a region that may have samples that have preserved traces of life. Potentially the iMars aims of collecting igneous rocks in addition to sedimentary material may pose challenges. For instance, Mawrth Vallis (Fig 2), which could be a leading candidate site for the exobiological purposes of the 2018 mission and MSR, may not easily allow sampling of igneous material. One way to resolve such an issue would be to redefine the priorities of MSR so that sampling of igneous material is assigned a lower priority. Potentially the iMars aims of collecting igneous rocks in addition to sedimentary material may pose challenges. For instance, Mawrth Vallis (Fig. 2), which could be a leading candidate site for the exobiological purposes of the 2018 mission and MSR, may not easily allow sampling of igneous material. One way to resolve such an issue would be to enable both rovers with sufficient mobility to reach rocks for a variety of interest.

[2] Preliminary Planning for an International Mars Sample Return Mission, Report of the International Mars Architecture for the Return of Samples (iMARS) Working Group, June 1, 2008

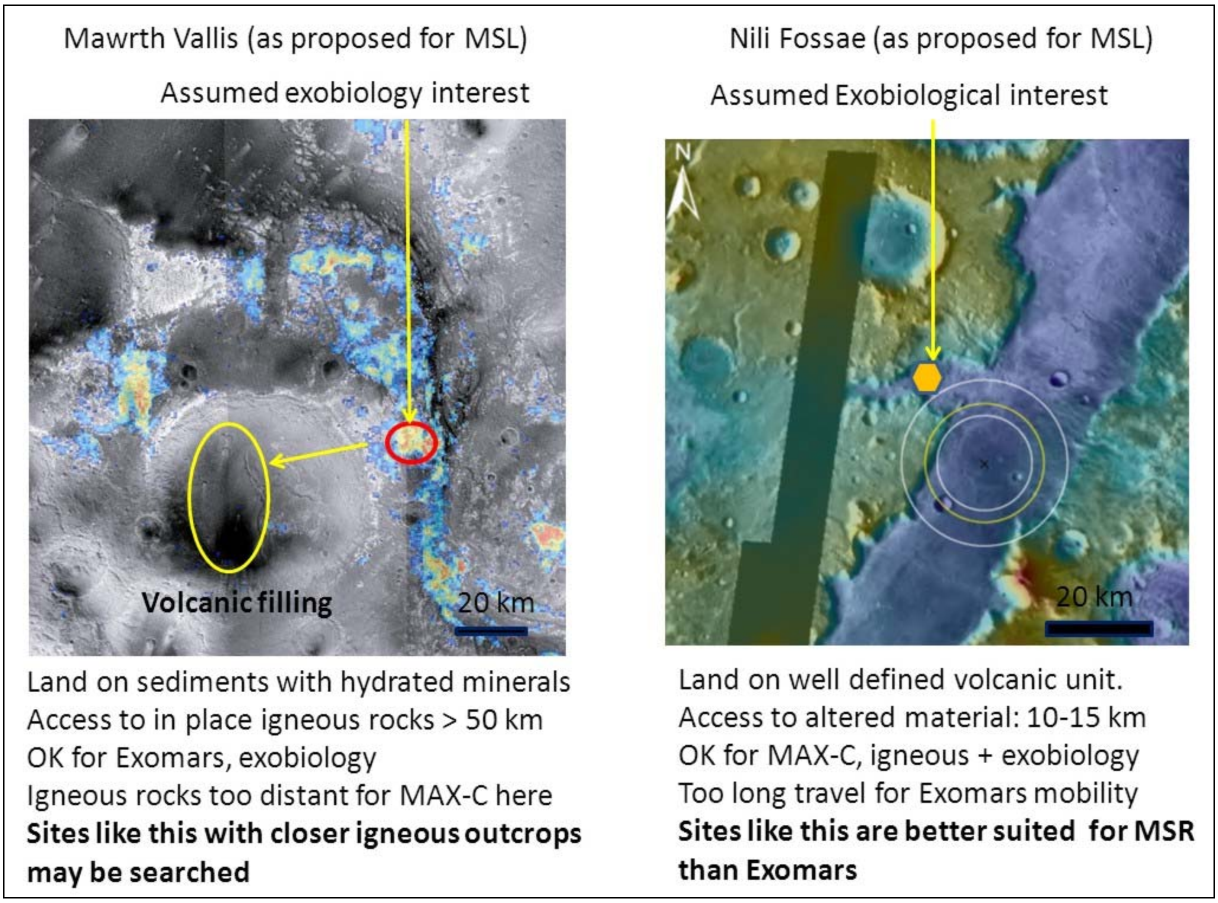

Figure 2: Image showing the principle of "go-to" and non "go-to" sites for the 2018 Dual Rover Mission (ESA's ExoMars and NASA's MAX-C rovers. a) Shows a non go-to situation where terrain with high astrobiology interest in Mawrth Vallis lies within the landing ellipse. Colours indicate hydrated minerals as seen from OMEGA/Mars Express data (Loizeau et al., JGR, 2007). Volcanic terrain (dark and pyroxene-bearing), having lesser interest for ExoMars, could be reachable outside the landing ellipse by the MAX-C rover by executing a long traverse. The traverse shown here may be too long, but similar sites with such diversity in closer proximity may be searched for. The reverse situation is shown in the topographic map of Nili Fossae b) where the landing ellipse contains volcanic terrain (low elevated terrain in blue) and the regions of astrobiology interest at the foothill of scarps lie outside the ellipse. This is a "go-to site" for exobiology, reachable with MAX-C mobility, but difficult to reach with the current mobility of the ExoMars rover.

Scenario #4: Minor bodies missions

Smaller solar system bodies, such as asteroids or the Martian moons Phobos and Deimos, place specific requirements on the mission and landing site selection process. Because of the low gravity environment, the landing itself poses fewer hazards (from a velocity and force point of view), but in many cases the lander has to be attached to the surface to stay in place —e.g. tethered. The same mission, shortly prior to landing, will generally acquire the surface data to confirm the landing site (Fig. 3). This means that the focus is initially on the definition of criteria for good landing sites rather than on identifying specific locations. The fast turnaround of remote sensing data required for the final selection of the site means that data formats should be pre-defined to be interchangeable, and data policy should allow for direct access to science data by a wider community than the individual instrument team.

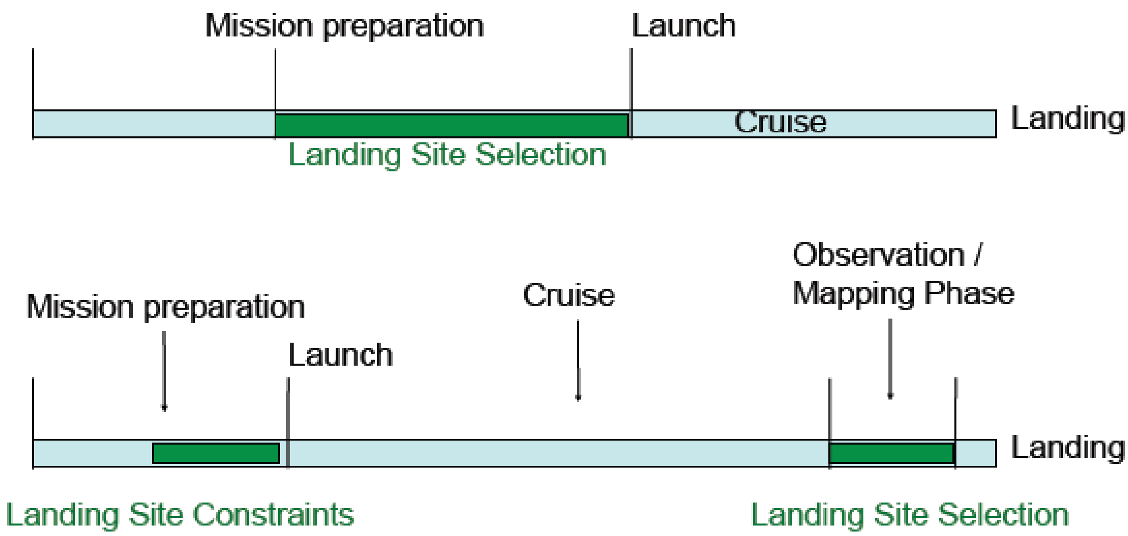

Fig. 3: The timeline for landing site selection for different mission scenarios. a) For Mars or Lunar missions, where landing site selection and characterization takes place prior to launch and cruise of the mission, b) for missions to minor bodies (asteroids, NEO, Phobos) where no, or very limited remote sensing data exists before the mission. Up to launch the focus is on the attributes, which constrain suitable landing sites. The final landing site selection is done during the observation phase, shortly prior to landing.

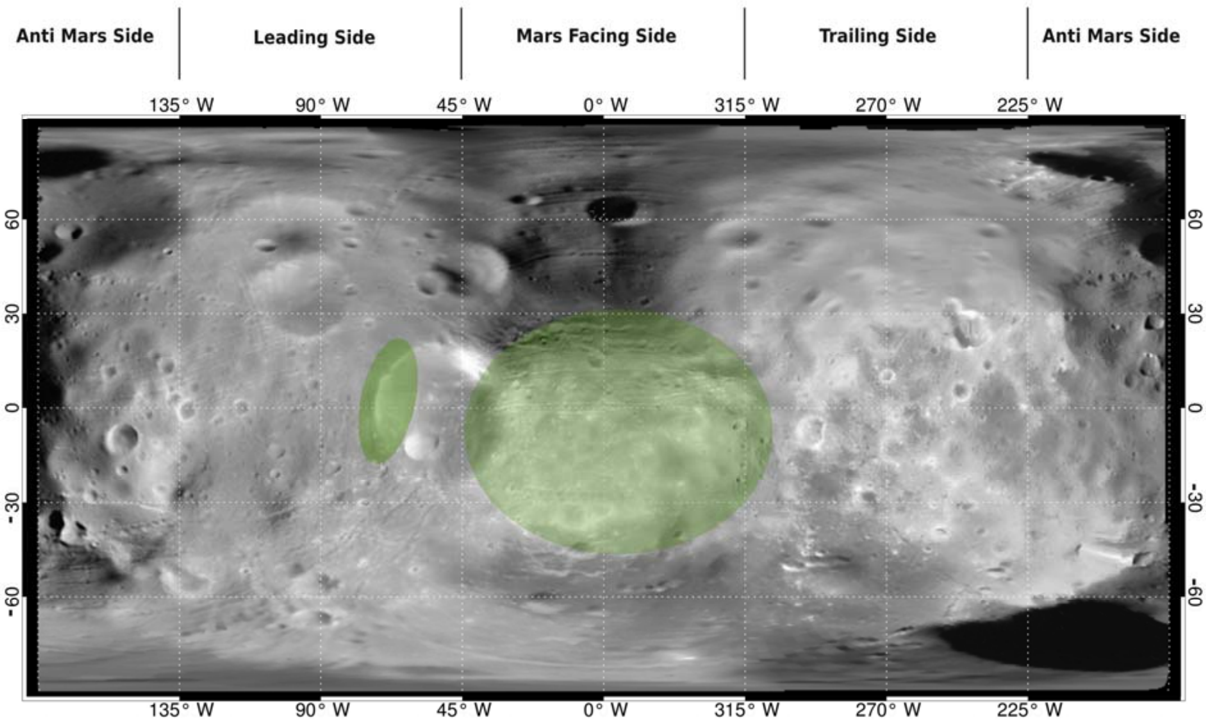

*Fig. 4: The surface of Phob*os as imaged by HRSC on Mars Express. The areas in green indicate potentially interesting landing areas.

Scenario #5: Commercial lunar missions/ Google Lunar X-prize

From a science perspective, boundary conditions for the landing site selection process for commercial Google Lunar X-prize missions differ substantially from typical institutional (NASA, ESA, JAXA etc.) science missions. Teams will have commercially rather than scientifically motivated reasons to aim for a landing at a particular site. For example, more prize money is available if a team lands close to a historic exploration site. In this scenario we therefore took a different approach to landing site selection. We created a map on which scientifically interesting target sites are overlapped with a map of the targeted locations of current X-Prize teams (Fig. 4). This type of mapping can provide (1) for every team, a list of top science areas that are closest to the proposed landing site, with a list of scientific instrumentation that would be best suited to address the key science issues at these sites (2) for each possible instrument suite, a list of landing sites that would give the highest potential scientific output. The Google Lunar X-prize in particular, and on the longer term commercial spaceflight in general, can be regarded as an opportunity for the science community to reach sites of scientific interest and to fly instruments with a high TRL level on a relatively short time scale.

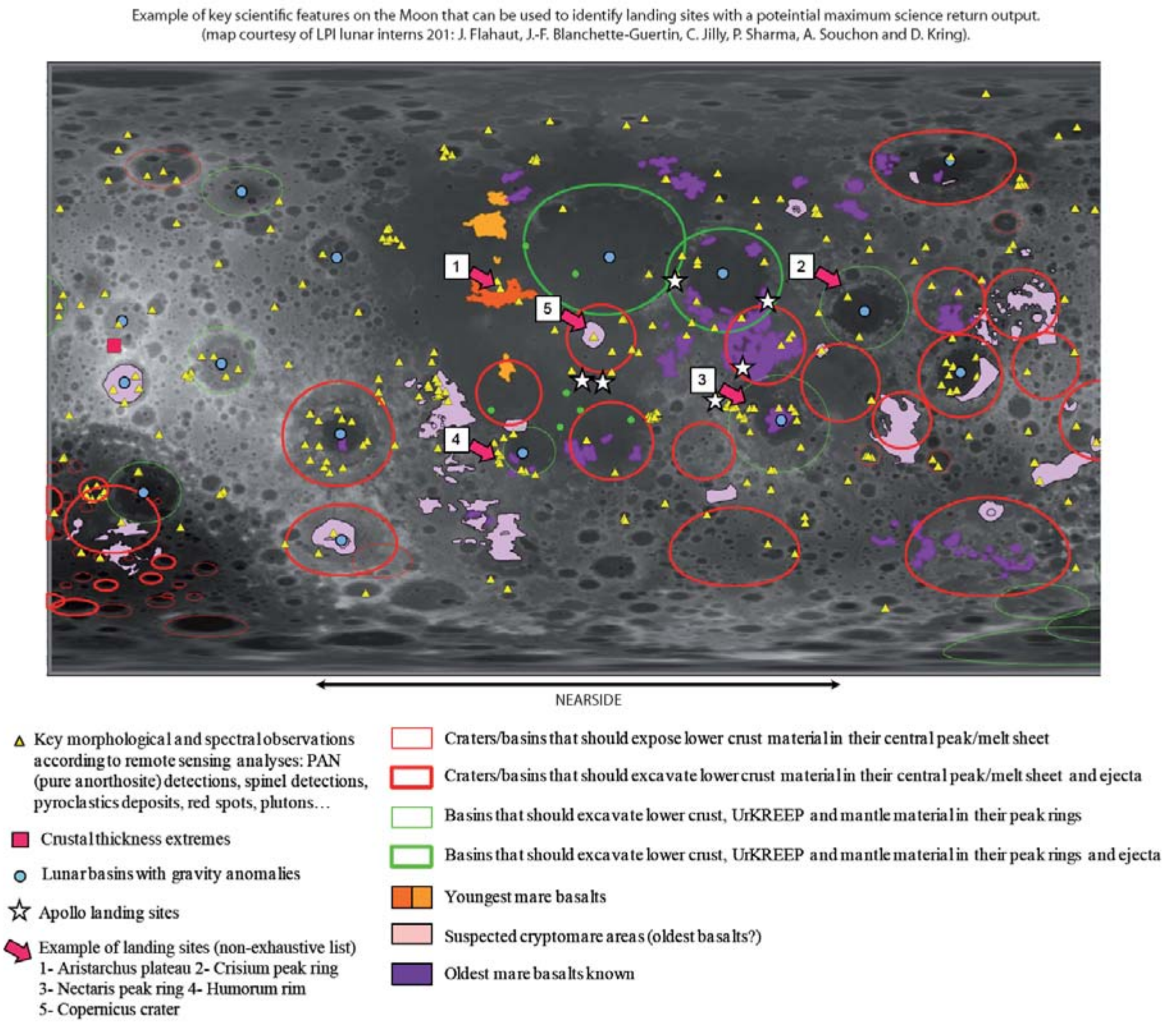

Fig. 4: Lunar map showing the preselected landing sites for various Lunar Google X-prize missions (black dots) in combination with a range of attributes which represent relevant scientific targets (colored areas and encircled basins). Map courtesy Jessica Flahaut (ENS Lyon).

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