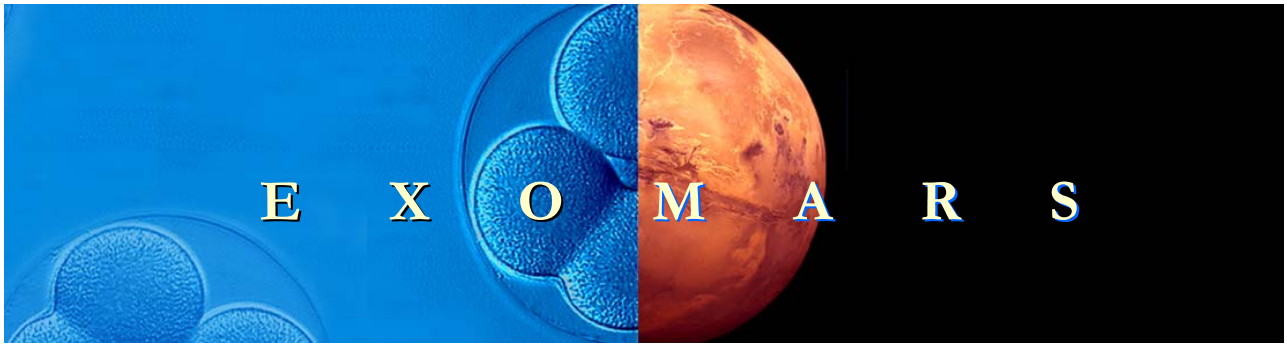

Science Management Plan

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1 INTRODUCTION AND SCOPE

Establishing whether life ever existed, or is still active on Mars today, is one of the outstanding scientific questions of our time. The ExoMars Programme seeks to timely address this important scientific goal and to demonstrate key flight and in-situ enabling technologies in support of the European ambitions for future exploration missions.

In support of the objectives of the Aurora Programme, the following technologies will be achieved:

- **Entry, Descent and Landing (EDL) of a payload on the surface of Mars;**
- **Surface mobility with a Rover;**
- **Access to the subsurface to acquire samples;**
- **Sample acquisition, preparation, distribution, and analysis.**

The ExoMars scientific objectives are:

- **To search for signs of past and present life on Mars;**
- **To investigate the water/geochemical environment as a function of depth in the shallow subsurface;**
- **To study Martian atmospheric trace gases and their sources.**

These objectives will be pursued as part of a broad cooperation with NASA. Two missions are foreseen within the ExoMars programme for the 2016 and 2018 launch opportunities to Mars.

The 2016 mission is ESA-led and launched by NASA. ESA will provide a Mars Orbiter and a 600-kg Entry, Descent and Landing (EDL) Demonstrator. The Orbiter will accommodate scientific instruments for the detection of atmospheric trace gases, the study of their temporal and spatial evolution, and the localisation of their source regions. The EDL Demonstrator will contain engineering sensors to evaluate the lander's descent performance and instruments to study the landing site.

The 2018 mission is NASA-led and includes the contribution of a rover from ESA. The ESA Rover will share the journey to Mars with a NASA rover. Both rovers will be integrated in the same aeroshell and will be delivered to the same site on Mars. This landing site will be selected jointly by ESA and NASA.

The ESA Rover will carry a comprehensive suite of analytical instruments dedicated to exobiology and geochemistry research named after Louis Pasteur. The Rover will travel several kilometres searching for signs of past and present life, collecting and analysing samples from within rocky outcrops and from the subsurface, down to a depth of 2 m.

This Science Management Plan specifies in detail the scientific management of the ExoMars programme, focusing on the way the payload is selected and implemented for the various mission elements, as a joint effort of the scientific community, the funding organisations, ESA and NASA. The modes of participation in the programme are addressed, as well as the responsibility of the ESA Project Manager, Project Scientist, and their teams vis-à-vis the implementation and exploitation of the instruments. Finally, the data rights of the involved scientists and their responsibilities for the public outreach activities are explained, as is the data analysis support policy.

Although adapted to specific ExoMars needs, this document draws extensively from [RD 6] and [RD 7] .

Once approved, the ExoMars Science Management Plan will become applicable to all parties wishing to participate in the ExoMars programme. Whenever mission or programmatic developments justify a revision, the ExoMars Science Management Plan will be updated and resubmitted, to the Advisory Bodies for endorsement and to the Programme Board (PB-HME) for approval.

2 DOCUMENTS

The documents in this section may be obtained from ESA by writing to Jorge.Vago@esa.int.

2.1 Applicable Documents

None.

2.2 Reference Documents

[RD 1] ExoMars Call for Ideas – Pasteur Instrument Payload for the ExoMars Rover Mission, Ref. CI-Pasteur-2003, 14 February 2003

[RD 2] Payload Confirmation Review (PCR) Board report, Ref. EXM-MS-PL-ESA-00005, Issue 1, 28 March 2007

[RD 3] Payload Confirmation Review #2 (PCR2) Review report, Ref. EXM-PL-REP-ESA-00028, Issue 1, 3 April 2009

[RD 4] Exobiology in the Solar System and the Search for Life on Mars, “Red Book” Report from the ESA Exo-biology Team Study, Ref. SP-1231, October 1999

[RD 5] JIDT (2009): Report from the 2016 Mars Orbiter Bus Joint Instrument Definition Team, October 2009

[RD 6] BepiColombo: Science Management Plan Approval, ESA/SPC(2004)9, 23 January 2004

[RD 7] Venus Express: Approval of Science Management Plan, ESA/SPC(2005)21, rev. 1, 2 May 2005

[RD 8] Council Resolution on the Rules concerning Information, Data and Intellectual Property, ESA/C(2002)3, 11 January 2002

3 EXOMARS SCIENCE OBJECTIVES

Establishing whether life ever existed, or is still active on Mars today, is one of the outstanding scientific questions of our time. The two missions of the ExoMars programme will address this important goal.

The ExoMars programme's scientific objectives are:

- **To search for signs of past and present life on Mars;**
- To characterise the water/geochemical environment as a function of depth in the shallow subsurface;
- To study Martian atmospheric trace gases and their sources.

The ESA Rover will address the first two scientific objectives on the surface of Mars, whereas the ESA Orbiter will pursue the third objective. However, each mission element can contribute useful complementary results to the other mission's measurements. The Rover will be able to provide some *in-situ* information on trace gases. Likewise, the Orbiter's findings will be relevant to the search for life objective.

ExoMars background information, including a brief historical summary of the work leading up to the programme's present status can be found in Annex 1.

3.1 The Search for Signs of Life on the Surface of Mars

In attempting to define an effective strategy to search for carbon-based life on Mars, a useful approach is to initially ponder separately the issues of past and present life detection; and subsequently, to look for a common thread that may suggest a way to address both cases.

3.1.1 Extinct Life

If life ever arose on the red planet, it probably did when Mars was warmer and wetter, sometime within the first billion years following planetary formation. Conditions then were similar to those when microbes gained a foothold on the young Earth. This marks Mars as a primary target for the search for signs of life in our solar system.

Unfortunately, on our planet, high-temperature metamorphic processes and plate tectonics have resulted in the reformation of most ancient terrains. It is very difficult to find rocks on Earth older than 3 billion years in good condition. Hence, the physico chemical record of the very early evolution of life on Earth is no longer accessible to us. The ensuing chemical and isotopic degradation of many putative bacterial fossils makes their reliable identification far from trivial.

A further complication is that a range of inorganic processes is known to result in mineral structures closely resembling simple biological shapes. This issue lies at the heart of a heated debate among palaeobiologists. Two recent examples that have attracted much attention are the early Achaean* rock specimens, obtained from the Pilbara region in Western Australia, claimed to contain Earth's oldest fossils to date; and the Martian meteorite ALH84001, whose alleged fossil microorganisms were seen worldwide in 1996: These structures are most likely not biogenic. The difficulty is that, in essence, we are looking for the exiguous remnants of minuscule, unshelled, uncompartmentalised beings whose fossilised forms can be confused with tiny mineral precipitates. It is therefore doubtful

Archean: The earliest part of the Precambrian era on Earth, approximately 3.8–2.5 billion years ago.

that the living origin of ancient candidate microfossils may be accurately established on the basis of their morphology alone. Although important, comparative anatomy by itself cannot be relied upon to provide sufficient proof.

Another useful clue may lie in the isotopic signature of carbon. Many life processes favour the assimilation of the light isotope, ^{12}C, over that having an extra neutron, ^{13}C. This gives rise to a higher concentration of ^{12}C in living cells relative to the one found in the surrounding dead environment. For instance, the enzymatic uptake of carbon during photosynthesis can result in a $^{12}C/^{13}C$ ratio significantly higher than the one used as standard for terrestrial abiotic material. Consequently, provided they can be isolated, carbon residues stemming from previously living matter may be recognised by their ^{12}C enrichment. However, the heating of rocks to high temperatures quickly converts any original cell material to graphite, degrading this signal and making it hard to interpret. For a useful interpretation of isotope biosignatures, a detailed understanding of the sources and sinks, as well as their temporal evolution, is crucial.

Some compounds synthesised by living organisms are so stable that they can last for billions of years after the parent cells have died and decomposed. It is not the whole molecule that survives, but rather the backbone of carbon atoms with its distinctive geometry. Typical examples are amino acids; the lipids that comprise cell walls; and some important pigments, such as bacteriochlorophyll and chlorophyll that absorb light to power photosynthesis in bacteria and plants. These telltale molecules are very common on our planet and can constitute very reliable biomarkers. Identifying one of them could prove as informative as finding a dinosaur bone.

Regrettably, a major problem with the study of biomarkers is that many decompose when exposed to temperatures greater than 200 °C. As already discussed, most Archean rocks on Earth have been heated beyond this value. Mars, on the other hand, has not suffered such widespread tectonic activity. This would imply that rock formations from the earliest period of Martian history, which have not been exposed to high-temperature recycling, are likely to exist. Consequently, well-preserved, ancient biomarkers may still be accessible for analysis.

Two of life's most important molecular building blocks —amino acids and sugars— can exist in left- and right-handed configurations called enantiomers✧ (Fig. 1) which, like a pair of gloves, are mirror images of one another. On Earth all living organisms use one enantiomer only: left-handed in the case of amino acids and right-handed for sugars. This property of homochirality❖ is essential for an efficient metabolism. Key life processes, such as protein synthesis and gene transcription, rely on amino acids and sugars having the correct spatial conformation to "shake hands" at molecular level with their counterparts. Conversely, synthetic chemicals prepared in the laboratory exhibit equal abundances of both right- and left-handed enantiomers —such a mixture is said to be racemic. Homochirality probably constitutes the most reliable indicator of the biological vs. abiotic origin of organic molecules. Surely, testing for homochirality becomes crucial when searching for life. However, as in the previous methods outlined, unfortunately also this one suffers when the sample is exposed to high temperatures or wet conditions for extended periods.

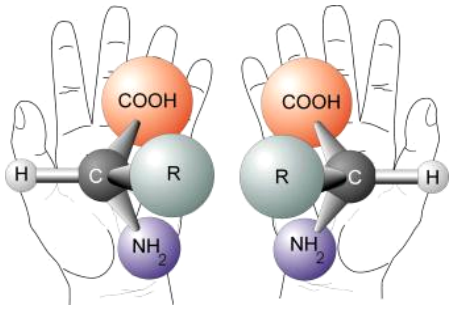

Fig. 1: Many of life's most important molecules can exist in left- or right-handed configurations. Credit: J. L. Bada, Scripps Inst. Ocean.

Summarising, the best chance to find signatures of ancient life on Mars is in the form of chemical biomarkers and fossil communities, either preserved underground or within surface rocks. A few life-detection methods —by no means exhaustive— were presented to illustrate how important it is to use complementary techniques that, combined, give more credence to the proposition of a sample's biological potential. Several independent lines of evidence are required to construct a compelling case. ExoMars must therefore pursue a holistic search strategy, attacking the problem from multiple angles, including investigations to characterise potential habitats, visual examination of outcrops (morphology), and spectrochemical composition analyses performed on well-selected samples.

✧*Enantiomer:* From the Greek *enantios*, denoting "opposite" or "opposing."

❖*Homochirality:* Compound word derived from Greek, meaning "same handedness."

Being liquid water a prerequisite for active life, good candidate locations to look for microfossils are terrains occupied by long-lasting bodies of water during Mars' early history. For example, within ancient lacustrine or marine sedimentary rocks that accumulated rapidly, where subsequent diagenesis* did not obliterate the original texture and compositional evidence; isotopic, organic, and mineralogical; of the deposition environment. It is trapped within exposed old sedimentary material and evaporitic deposits that the record of ancient Martian life, if it ever existed, is likely to be preserved.

3.1.2 Extant Life

In 1976, the twin Viking landers conducted the first *in-situ* measurements focusing on the detection of organic compounds and life on Mars. The Viking biology package contained three experiments, all looking for signs of metabolism in soil samples. One of them, the Labelled-Release Experiment produced very provocative results. If other information had not been also available, these data could have been interpreted as proof of biological activity. However, theoretical modelling of the Martian atmosphere and regolith chemistry hinted at the existence of powerful oxidants, which could more-or-less account for the results of the three biology package experiments. The biggest blow was the failure of the Viking Gas Chromatograph Mass Spectrometer (GCMS) to find evidence of organic molecules at the parts-per-billion level. Although not intended as a life-detection experiment, the GCMS measurements were regarded to be inconsistent with a biochemical explanation for the Labelled-Release data. It must be stressed that the Viking GCMS was not designed to search for living cells, but rather for the gaseous pyrolytic degradation products of organic substances. Hence, this instrument could have missed significant amounts of non-volatile organic compounds. Recent work suggests that the sensitivity of the Viking GCMS may have been insufficient to detect the organics released by heat from up to 30 million bacteria per gram of soil. This number reflects the concentration of microorganisms detected, for instance, in permafrost samples on Earth. Although the interpretation that the Labelled-Released results may be due to the action of highly reactive oxidants in the regolith is still debated; nevertheless, with few exceptions, the majority of the scientific community has concluded that the Viking results do not demonstrate the presence of life.

Numerous attempts have been made in the laboratory to simulate the reactions observed by the Viking biological package. While some have reproduced certain aspects of the data, none has succeeded entirely. An oxidant experiment was part of the Russian Mars '96 scientific payload. Alas, a launcher failure meant the loss of that opportunity to characterise the reactivity of the Martian soil. Incredibly, almost forty years after Viking, the crucial chemical oxidant hypothesis remains still untested. The ExoMars Rover will therefore include a powerful instrument to study organics and their relation to oxidants distribution on Mars.

Undoubtedly, the present environment on Mars is exceedingly hostile for the widespread proliferation of surface life it is simply too cold and dry, not to mention the large doses of UV radiation. Notwithstanding these hazards, basic organisms may still flourish in protected places: deep underground; at shallow depths, in especially benign environments; or within rock cracks and inclusions.

Perhaps a good first step is to consider Earth ecosystems with conditions approximating those of the Red Planet. In this regard, it is the frigid desert of the Antarctic dry valleys (77° 45' S) that bears the closest resemblance to the Martian environment today. This region has temperatures varying between –15 and 0°C in the summer, and as low as –60°C during the winter, with a relative humidity of 16 to 75%. The melting of the infrequent snow coverage on rocks is the main source of water for life there.

Fig. 2: Example of a cryptoendolithic microorganism of the McMurdo Dry Valleys. These cold-adapted algae live in favourable microclimates, just beneath the surface of porous rocks facing the Sun. Credit: R. Kinne, NSF.

The primary producers are photosynthetic endolithic microbial communities dominated by cryptoendolithic lichens. These microorganisms colonise a narrow zone a few millimetres beneath the surface of rocks (Fig. 2). This habitat provides a favourable microclimate, and is well protected from the harsh outside environment (strong winds, temperature fluctuations,

Diagenesis: The physical and chemical changes occurring in sediments between the time of deposition and petrification.

desiccation, and UV radiation). Cryptoendolithic communities are only found in weathered or porous rocks because only these types of rocks offer the necessary substrate to colonise their interior, the permeability for the uptake of liquid water and moisture, and the translucent property required for the photosynthetic primary producer. Usually, endoliths grow only on the faces of rocks where the highest insolation is received: in Antarctica, North-facing or horizontal. Water is provided to the rock by blowing snow or frost, which melts into the rock when it is warmed by sunlight. During the summer, freeze/thaw transitions are common. The endoliths are wetted either by equilibration with the high humidity air in the rock, or by direct moisture uptake after snow/frost melt.

Life could have escaped the deteriorating climatic conditions on the surface of Mars by finding refuge in habitats that are very similar to those colonised by cryptoendolithic communities in Antarctica. Whether this ever happened, will be part of the investigations performed by the ExoMars Rover mission.

3.1.3 The Martian Environment and the Need for Subsurface Exploration

For organisms to have emerged and evolved, liquid water must have been present on Mars. Without it, most cellular metabolic processes would not be possible. In the absence of water, life either ceases or slips into a quiescent mode. Hence, the search for extinct or extant life automatically translates into a search for liquid water-rich environments, past or present.

The strategy to find traces of past biological activity rests on the assumption that any surviving signatures of interest will be preserved in the geological record, in the form of buried/encased remains, organic materials, and fossil communities. Similarly, because current Martian surface conditions are hostile to most known organisms, also when looking for signs of extant life, the search methodology should focus on investigations in protected niches: in the subsurface and within surface outcrops. Therefore, the same sampling device and instrumentation can adequately serve both types of studies.

As will be explained in the next paragraphs, the rover's surface mobility and the 2-m vertical reach of the drill are both crucial for the scientific success of the mission.

The ExoMars rover will search for two types of life-related signatures: morphological and chemical. This will be complemented by an accurate determination of the geological context.

Morphological information related to biological processes may be preserved on the surface of rocks. Possible examples include the bio-mediated deposition of sediments, fossilised bacterial mats, stromatolitic mounds, etc. Such studies require mobility and an imaging system capable to cover from the metre scale down to a sub-millimetre resolution (to discern micro-textural information in rocks).

An effective chemical identification of biomarkers requires access to well-preserved organic molecules. Because the Martian atmosphere is more tenuous than Earth's, three important physical agents reach the surface of Mars with adverse effects for the long-term preservation of biomarkers: 1) The ultraviolet (UV) radiation dose is higher than on our planet and will quickly damage potential exposed organisms or biomolecules. 2) UV-induced photochemistry is responsible for the production of reactive oxidant species that, when activated, can also destroy biomarkers; the diffusion of oxidants into the subsurface is not well characterised and constitutes an important measurement that the mission must perform. Finally, 3) ionising radiation penetrates into the uppermost metres of the planet's subsurface. This causes a slow degradation process that, over many millions of years, can alter organic molecules beyond the detection sensitivity of analytical instruments. Please note that the ionising radiation effects are depth dependent: the material closer to the surface is exposed to a higher dose than that buried deeper.

A major goal of ExoMars is to study ancient (older than 3 billion years) sedimentary rock formations and evaporitic deposits. However, it is only trapped in the subsurface for long periods that the record of early Martian life, if it ever existed, is likely to escape radiation and chemical damage. Studies show that a subsurface penetration in the range of 2 m is necessary to recover well-preserved organics from the very early history of Mars.

Additionally, it is essential to avoid loose dust deposits distributed by aeolian transport. While driven by the wind, this material has been processed by UV radiation, ionising radiation, and potential oxidants in the atmosphere and on the surface of Mars. Any organic biomarkers would be highly degraded in these samples.

For all the above reasons, the ExoMars drill will be able to penetrate and obtain samples from well-consolidated (hard) formations, at various depths, from 0 down to 2 m.

Fig. 3 presents an artistic view of the Rover and drill on the surface of Mars. The Rover will monitor and control torque, thrust, penetration depth, and temperature of the drill bit. Grain to grain friction in a continuous rotary drill can generate a heat wave in the sample, destroying the organic molecules that ExoMars seeks to detect. The drill therefore has the possibility to implement a variable cutting protocol that can dissipate heat in a science-safe manner. The drill's full 2-m extension is achieved by assembling four sections: one drill tool rod, with an internal shutter and sampling collection capability, plus three extension rods. The drill is also equipped with an IR spectrometer for mineralogy studies inside the borehole.

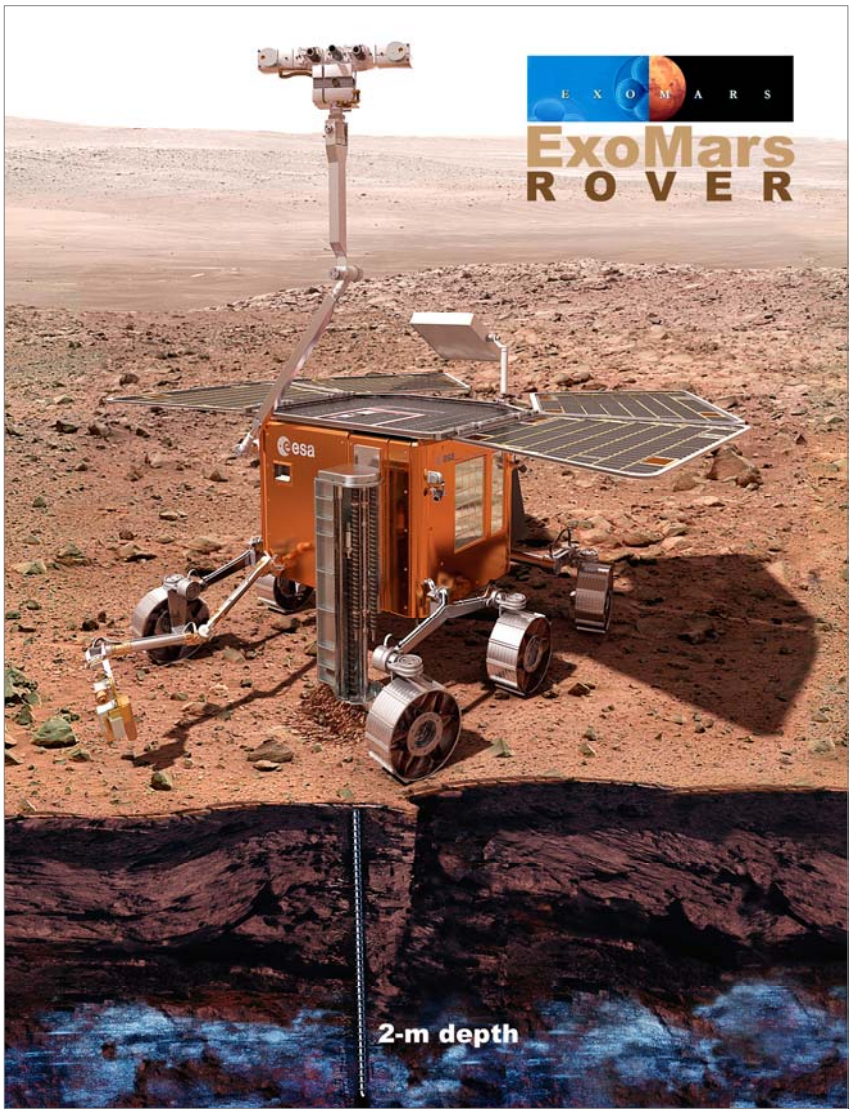

Fig. 3: Artist view of the ExoMars Rover shows the drill obtaining a sample from the Martian subsurface.

3.1.4 Rover Scientific Measurements

Fig. 4 shows the link between the Rover's science objectives and the measurement capabilities of its Pasteur payload. The instruments are presented in Annex 2.

SCIENCE OBJECTIVE	SCIENCE INVESTIGATION	REQUIRED MEASUREMENTS	PLANNED MEASUREMENT APPROACH
O1: Search for signs of past and present life	**I1**: Search for complex organic molecules at depth	**M1:** Detect the presence of C-C, C-H, C-N, and N-H bonds	**A1:** Determination of the Raman spectra of subsurface samples **A2**: IR spectral analysis of subsurface samples **A3:** IR spectral analysis performed in drill borehole
		M2: Detection of amino-acids, PAHs, and other organic material	**A1:** Laser-desorption detection of organic material from subsurface samples **A2**: Heat evolved detection of aminoacids and other organics **A3:** Spectral identification of pigments and fluorescense signature of organics
		M3: Identify specific organic biomarkers	**A1:** Ppb-level mass determination of organic fragments released from drilled material **A2:** Spectral identification of specific pigments **A3:** Liquid extraction and detection of specific biomarkers
	I2: Identify bio-mediated processes in rocks	**M1:** In situ assessment of the presence of fossils and/or biofabrics in rocks and soils	**A1:** Target characterisation at panoramic scale, with sub-mm texture observations **A2**: Spectral signatures of surface rocks **A3.** Determine the oxidation state of rocks by measuring Fe0, Fe2+, Fe3+
	I3: Search for complex organic molecules on surface targets	**M1:** Detect the presence of C-C, C-H, C-N, and N-H bonds	**A1:** Determination of the Raman spectra of samples obtained from oucrops **A2**: IR spectral analysis of outcrop samples
		M2: Detection of amino-acids, PAHs, and other organic material	**A1:** Laser-desorption detection of organic material from surface samples **A2**: Heat evolved detection of aminoacids and other organics **A3:** Spectral identification of pigments and fluorescense signature of organics
		M3: Identify specific organic biomarkers	**A1:** Ppb-level mass determination of organic fragments released from drilled material **A2:** Spectral identification of specific pigments **A3:** Liquid extraction and detection of specific biomarkers
	I4: Search for atmospheric signatures of possible biological significance	**M1:** Detect atmospheric trace gases of possible biological relevance	**A1**: Measurement of atmospheric trace gases
	I5: Determine geological context of explored sites	**M1:** Field geologic mapping and correlation with analytical laboratory measurements	**A1**: Site characterisation at panoramic scale, with observations down to sub-mm scale **A2:** Subsurface soundings to establish stratigraphy **A3:** Analysis of surface outcrop samples
	I6: Establish organic cleanliness of sample path	**M1:** *In-situ* verification of abscense of Earth organic contaminants	**A1**: Ppb-level organics investigation on mission blanks
O2: Characterise the water/geochemical environment as a function of depth in the shallow subsurface (0–2 m depth)	**I1:** Detect the presence of water	**M1:** Detect water in the subsurface	**A1:** Subsurface sounding down to 3 m at cm-scale resolution along the rover path **A2:** Possible deeper sounding of the subsurface **A3:** Search for water by GC-MS analysis. **A4:** Search for H_2O spectral signatures in drill samples
	I2: Search for water-bearing minerals at different depths	**M1:** Identification of rocks and borehole material	**A1:** Wide angle + high resolution images **A2**: Measure spectral signature of OH and H_2O
		M2: Mineralogic composition of drilled samples	**A1:** Spectral analysis of drilled samples at the mineral grain size level **A2**: Elemental analysis of drill samples **A3**: Analysis of gases released by heating
	I3: Degree of subsurface layering and mineralogy	**M1:** Physical characteristics/ mineralogy/ stratigraphy of the subsurface	**A1**: Subsurface sounding down to 3 m at cm-scale resolution along the rover path **A2:** Possible deeper sounding of the subsurface
		M2: Mineralogy/chemistry/biochemistry of the drilled samples	**A1**: Spectral analysis of drill samples at the grain size level **A2**: Elemental analysis of drill samples **A3:** Analysis of borehole as a function of drilling depth **A4**: Search for biominerals by step heating
	I4: Record preservation state as a function of depth	**M1**: Determine the chemical nature and reactivity of oxidants (and free radicals) **M2:** Estimate ionising radiation effects	**A1**: Detect iron-bearing minerals **A2**: Search for H_2O_2 and other GC-MS analysable oxidants **A3:** Characterise cosmic ray dose

Fig. 4: Link between the Rover science objectives and the measurement capabilities of its instrument payload.

3.1.5 Rover Science Mission

The scientific success of the ExoMars Rover depends on being able to land safely on a scientifically interesting location. An appropriate landing site can only be identified on the basis of remote sensing information. Since ExoMars is a "search for life" mission, candidate sites must contain evidence suggestive of a past or present habitable environment, supported by both morphology and mineralogical composition information. A good landing ellipse would include multiple instances of outcrops whose composition is considered suitable for the long-term preservation of biomarkers (e.g. clays, sulphates, etc.) in association with long-lasting fluvial, lacustrine, or hydrothermal signatures. However, it is the buried deposits that constitute the primary science target.

The mission strategy to achieve the ExoMars Rover's scientific objectives is:

1. To land, or to be able to reach, a location possessing high exobiology interest for past or present life signatures, i.e. access to the appropriate geological environment.
2. To collect scientific samples from different sites, using a rover carrying a drill capable to reach well into the subsurface and into surface rocky outcrops.
3. At each site, to conduct an integral set of measurements at multiple scales (Fig. 5): beginning with a panoramic assessment of the geological environment, progressing to smaller-scale investigations on surface outcrops, and culminating with the collection of well-selected subsurface (or surface) samples to be studied in the rover's analytical laboratory.

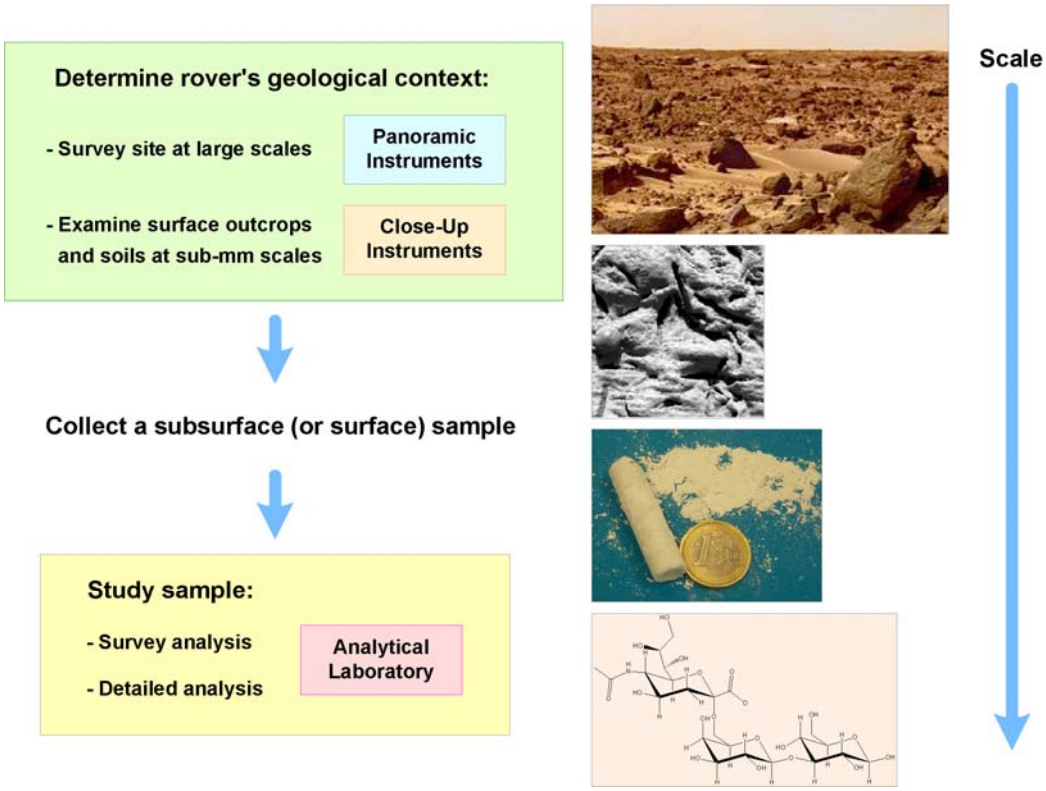

Fig. 5: The ExoMars Rover surface exploration scenario: The Rover will conduct measurements at multiple scales, beginning with a panoramic assessment of the geological environment, progressing to smaller-scale investigations on surface outcrops, and culminating with the collection of well-selected subsurface (or surface) samples to be studied in the rover's analytical laboratory.

If any organic compounds are detected on Mars, it will be important to show that they were not brought from Earth. The only way to reliably demonstrate that the rover is free from contaminants is to perform an initial measurement run using a blank sample. For this reason, the ExoMars rover will carry a number of blank calibration samples. Upon landing, one of the first science actions will be for the drill to pass a blank sample to the analytical laboratory. After performing a full investigation, the results should indicate “no life” and “no organics.” Failure to obtain this first negative reading could invalidate any search-for-life findings.

Throughout its nominal 180-sol mission, the ExoMars rover will be able to perform 6 Experiment Cycles (each involving the acquisition and analysis of a surface and a subsurface sample at an individual site); and 2 Vertical Surveys (each vertical survey consists of obtaining and analysing five subsurface samples at 50 cm depth increments, from 0 to 200 cm, to study variations with depth at one location).

A typical Experiment Cycle scenario can be summarised as follows: Assuming the Rover has reached a desired location, it conducts a panoramic survey with the PanCam Wide Angle Cameras (WAC), followed by the acquisition of more detailed visual information on potential targets of interest with PanCam’s High-Resolution Camera (HRC). On the basis of these measurements, Ground commands the Rover to approach an outcrop. While moving, the Rover obtains subsurface scans at regular intervals using the shallow-ground penetrating radar WISDOM. Having reached the outcrop, PanCam HRC is used to document the formation; CLUPI acquires high-resolution images to characterise the depositional environment and search for morphological biosignatures. The Rover collects a sample from the outcrop with the drill and delivers it to the Analytical Laboratory Drawer (ALD). The sample is crushed and the particulate matter is analysed by the ALD instruments.

Thereafter, a detailed WISDOM campaign, following a grid pattern, allows characterising the subsurface stratigraphy. With this information, Ground selects an appropriate site for obtaining a subsurface sample with the drill. The average depth is assumed to be 1.5 m. Ma_MISS studies the mineralogy of the borehole walls. The sample is retrieved, passed on to the ALD and crushed. MicrOmega IR performs a detailed analysis of the mineral grain assemblages and identifies those having a high potential for the preservation of organics. Raman and MOMA-LDMS target their laser shots using this information. MARS-XRD establishes the sample’s mineralogy. In case Raman or MOMA-LDMS in survey mode identify interesting organic signatures, a more detailed analysis with MOMA-LDMS and MOMA-GCMS is performed. LMC is reserved only for the most promising samples, possibly those associated with Vertical Surveys where MOMA has detected organic compounds.

3.1.6 Rover Science Conclusions

On Earth, microbial life quickly became a global phenomenon. A similar explosive process could have occurred on the young Mars. Perhaps, even more interesting would be the discovery and study of life forms that have successfully adapted to modern Mars. However, this presupposes the prior identification of geologically suitable, life-friendly locations where it can be demonstrated that liquid water still exists, at least for short periods, throughout the year. Today we do not know of any such place. For these reasons, the first exobiology science team advised ESA in the “Red Book” of 1999 [RD 4] to focus mainly on the detection of extinct life; but also, to build enough flexibility into the mission design to be able to identify signatures of present life.

The successful NASA Mars Exploration Rovers (MER) have demonstrated the past existence of wet environments on Mars using a geologically oriented instrument package. Their results have persuaded the scientific community that mobility is a must-have requirement for future missions. Recent discoveries from ESA’s Mars Express spacecraft have revealed multiple deposits containing salt and clay minerals that can only form in the presence of liquid water. This reinforces the hypothesis that ancient Mars may have been wetter, and possibly warmer, than it is today. NASA’s Mars Science Laboratory (MSL), planned for a 2011 launch, will study surface geology and organics, with the goal of identifying habitable environments. The ExoMars Rover constitutes the next logical step in Mars exploration. It will have instruments to investigate whether life ever arose on the red planet. It will also be the first mission combining mobility and access to subsurface locations where organic molecules may be well-preserved; thus allowing, for the first time, to investigate Mars’ third dimension: depth. This alone is a guarantee that ExoMars will break new scientific ground.

The ExoMars Rover will also provide crucial science results to prepare for an international Mars Sample Return (MSR) mission, as it will establish whether or not it is important that the MSR samples be collected from the subsurface.

3.2 The Study of Martian Atmospheric Trace Gases

Recent observations from the Planetary Fourier Spectrometer (PFS) on ESA's Mars Express and from very high spectral resolution spectrometers, using ground-based telescopes, have detected variable amounts of methane in the atmosphere of Mars. Based on photochemical models and on the current understanding of the composition of the Martian atmosphere, methane has a chemical lifetime of ~300–600 years, which is very short on geological time scales. Thus, its presence indicates a subsurface source that has recently (geologically speaking) released methane into the atmosphere. There are both geochemical and biochemical processes that could produce methane in the subsurface —its presence is not sufficient to establish the nature of the source. Current photochemical models cannot explain the reported rapid space and time variations in atmospheric methane concentration. Whether geochemical or biochemical in origin, methane observations indicates a dynamically active subsurface on Mars today.

The scenario presented in this document is the result of the work performed by the Joint Instruments Definition Team (JIDT), a team of scientists supported by ESA, NASA, the ExoMars Project, and the Mars Programme Office of the Jet Propulsion Laboratory. More information can be found in [RD 5] .

3.2.1 Orbiter Scientific Objectives

The broad science themes of the 2016 Orbiter mission include:

- Detection of a broad suite of atmospheric trace gases (with high sensitivity)
- Characterisation of their spatial and temporal variation
- Localisation of sources of key trace gases?

These trace gas science objectives are described in more detail below:

Detection:

- Measure with very high sensitivity the following molecules and their isotopomers: H_2O, HO_2, H_2O_2, NO_2, N_2O, CH_4, C_2H_2, C_2H_4, C_2H_6, H_2CO, HCN, H_2S, OCS, SO_2, HCl, CO, O_3
  - Improve by an order of magnitude detection capabilities and upper limits for a broad range of trace gases.
  - For many species this requires detection sensitivities in the parts-per-trillion range.
- Because current photochemical models cannot explain the present observations of methane, measurements of additional gases may be proposed in response to an AO.

Characterisation:

- Spatial and temporal variability of photochemical processes requires:
  - Measurements to capture effects occurring on different time scales: a) daily (i.e., local time) due to diurnal variations of insolation; b) day-to-day and weeks due to atmospheric transport; and c) seasonal due to changes in sunlight and atmospheric aerosol and water vapour distributions.
  - Separating seasonal and local time effects with observations covering the diurnal cycle multiple times in a Mars year.
  - Representative measurements of different environments, from the polar regions to the equator, are also needed.
- A powerful tool for characterizing the relative roles of different photochemical processes is to correlate concentration measurements of trace gases with observed environmental variations of temperature, dust and ice aerosols and of source gases.

Localisation of Sources:

- Inverse modelling can link observed concentration patterns to regional transformations (e.g., in dusty air) or to localized sources; it requires simulations using circulation models constrained by dust and temperature observations with good vertical resolution.

- Mapping multiple tracers (e.g., aerosols, water vapour, CO, CH_4) with different photochemical lifetimes and correlations will help constrain model simulations and identify source/sink regions.
- Identifying very localised sources may require tracing some species (e.g., methane) at the ~1 part-per-billion concentration level.

Priority is given to a sensitive survey of the trace gases in the atmosphere and to characterising their variations over much of the globe on diurnal, day-to-day and seasonal time scales.

3.2.2 Orbiter Scientific Measurements

The scientific measurements listed below are considered necessary to fulfil the scientific objectives of the Orbiter mission:

1) Solar occultation and nadir mapping measurements: These provide the best means for surveying atmospheric composition with high sensitivity, as they measure absorption of a bright source (sunlight) passing through a large atmospheric path (along the tangent occultation path), with very high spectral resolution to reduce the effects of line mixing, etc. A Solar occultation Fourier Transform Interferometer Radiometer (SFTIR) can cover a broad spectral interval, enabling detection of a broad suite of trace gases. Other solar occultation techniques, like Solar Limb and Nadir Infrared (SLNIR), exploit narrower spectral intervals for specific trace gases, but may also be used to look nadir at sunlight reflected from the surface, or at sunlight scattered into their views of the atmospheric limb. While these typically have less sensitivity (or higher thresholds), they provide a link from the solar occultation measurement points (2 per orbit) to extended latitude coverage on each orbit.

2) Thermal emission measurements: Sub-millimetre (Sub-mm) and thermal infrared (TIR) spectrometers can be used to look at atmospheric thermal emission when viewing nadir or at the atmospheric limb. These characterise the atmospheric state by providing vertical profiles of temperature and of key source gases, such as water vapour. Sub-millimetre measurements have the advantage of being largely unaffected by the presence of atmospheric dust. Thermal IR instruments have the advantage that they can map the distribution of atmospheric aerosols. Both sub-millimetre and thermal IR spectrometers can measure selected minor species such as methane (TIR-spec) and carbon dioxide (Sub-mm). The sub-millimetre in its limb-view mode could also measure atmospheric winds, which would provide a novel constraint on simulations of atmospheric transport. Thermal IR radiometers (TIR-rad) viewing the atmospheric column and limb can provide vertical profiles of dust and ice concentration plus profiles of atmospheric temperature and surface temperatures. Radiometers are less demanding than spectrometers in terms of data volume, but typically have gas composition sensitivity to only water vapour and carbon dioxide.

3) Visual monitoring of atmospheric phenomena: Wide-angle cameras (WAC) can provide daily monitoring of the global atmosphere and its regional atmospheric phenomena: clouds, storm systems, aerosol layers, dust storms and boundary layer phenomena, such as dust devils and wind streaks. Viewing from horizon to horizon provides important context for the profiling and limited area mapping instruments.

4) High-resolution surface imaging: Very high spatial resolution imaging or mapping instruments (e.g., cameras and multi-beam active lasers) can provide geological context and location of small-area sources, should they exist (e.g. a volcanic vent, tectonic rift, or recent impact crater). However, such high spatial resolution produces large data volumes for coverage of even very small regions. A high-resolution camera could provide geologic characterisation aided by colour and by stereo imaging (HRCSC). However, to achieve adequate signal-to-noise at these high spatial resolutions probably requires Time-Delayed-Integration (TDI), which implies the need for precision pointing along the spacecraft ground track in order to sum columns of the CCD detector. The possible implementation of such imaging capability should not compromise trace gas measurements or become a driver for the Orbiter design.

Fig. 6 shows the link between the trace gas science objectives and the measurement capabilities of the instrument concepts described above.

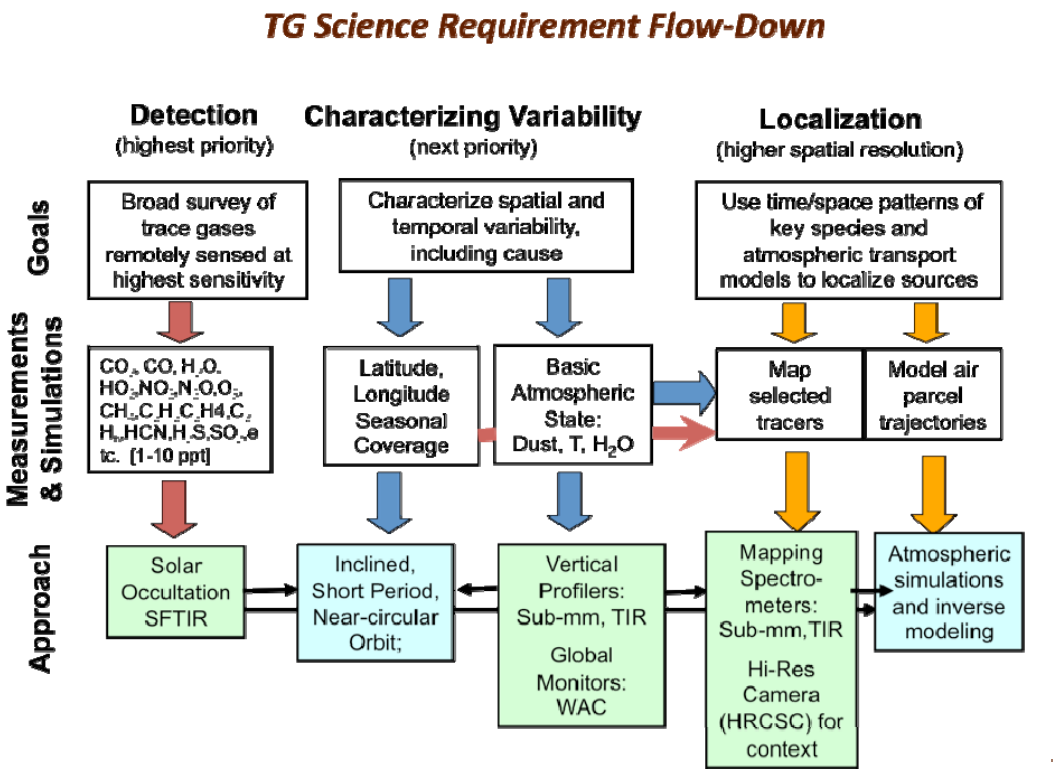

Fig. 6: Link between the trace gas science objectives and the measurement capabilities of the model payload instrument concepts. Credit: NASA/ESA.

Representative instruments capable of performing the measurements outlined above have been considered by the JIDT. All of these "straw man" instruments have heritage from planetary and/or Earth orbiter missions. Based on that flight experience, estimates of mass, power, data volume, and key pointing requirements have been determined for the purpose of sizing the spacecraft's capabilities. These are summarized in Annex 3.

The JIDT also ranked the priority of the measurements with respect to the trace gas science objectives. These are also presented in Annex 3.

The highest priority was assigned to measurements of a broad suite of trace gases with high sensitivity, both to establish the atmospheric inventory, but also to provide insights into the nature of the trace gas source through the detection of suites of gases or through ratios of gases and isotopes (e.g., volcanic in nature or biogenic?). The ability to map certain key species (e.g., methane) outside the limits of solar occultation geometries was also given high priority, because of the limited spatial coverage possible even with an orbit designed to facilitate solar occultation measurements.

The second priority is for measurements and low-resolution imaging of the atmospheric state (aerosols and temperature) and for mapping of key trace gas species other than methane. Besides source gases like water vapour, candidates include CO, H_2O_2, SO_2 and higher order hydrocarbons. Since the present photochemical models do not reproduce the reported methane variations, it is difficult to reach a consensus on which trace gas species should be mapped; responses to an Announcement of Opportunity (AO) might successfully argue for species not listed here. Finally, while some redundancy in measuring key trace gases is useful, there can be some trade-off between the different instrument approaches, but more than one instrument technique would be required.

The third priority corresponds to high-resolution imaging. Its utility for trace gas science is in providing geological context for localised sources, which may or may not exist. While important objectives exist for surface change science (detection of new impacts, new or varying aeolian features, monitoring of polar ice deposits), extended imaging is difficult to accommodate within the capabilities of the current 2016 orbiter bus concept. However, the JIDT concluded that there might be a niche for a camera that achieves high-resolution ground sampling. Colour and stereo capability would significantly increase the value of surface observations, though they expand substantially the data volume returned.

3.2.3 Orbiter Science Mission

The science objectives and the measurement considered have three distinct observing modes: 1) Solar occultation viewing [SFTIR, SLNIR]; 2) repeated vertical profiling, typically including nadir and space views [TIR, Sub-mm, SLNIR]; and 3) imaging along [HRCSC] or orthogonal to [WAC] the spacecraft track.

Visual imaging instruments would observe on the dayside, and the solar occultation instruments would observe at two occultation points (sunrise/sunset) per orbit. The limb and nadir viewing instruments measuring thermal emission from the atmosphere would typically conduct measurements throughout each orbit on both the day and night sides.

To achieve good vertical and longitudinal resolution for the limb/nadir viewing instruments, and to achieve high-spatial resolution imaging, requires an circular orbit ~400 km or lower. A fixed ground track, one that repeats each day, is not favoured, as areas between the ground tracks are always viewed obliquely. A rapid repeat cycle of 3–5 days is preferred, in which the longitudinal span between two adjacent orbits on one day is divided in roughly equal portions of 3–5 parts over that period.

The science portion of the ExoMars Orbiter mission will last one Martian year. Thereafter, the spacecraft's main task will become the provision of data relay services for the 2018 rovers and future landers.

3.2.4 Orbiter Science Conclusions

A scientifically exciting and credible mission can be conducted within the proposed mission concept of a 2016 science/telecom Orbiter delivering an EDL Demonstrator on direct entry to Mars. An appropriate science payload can be selected in response to an open competition. The scientific promise of this mission is that it will reveal just how active the Mars subsurface is, with the hope that it will explain the nature of that activity —geochemical or biological.

3.3 Descent and Environment Science with the EDL Demonstrator

The 2016 mission scenario foresees a 600-kg class Entry, Descent, and Landing (EDL) Demonstrator to be released by the Orbiter from its hyperbolic arrival trajectory, approximately 3 days before touchdown. Because this mission element constitutes a technological development rather than a science platform, the nature of the sensors that it can accommodate is relatively simple. The EDL Demonstrator will rely on batteries to power instruments after landing for a nominal surface mission duration not exceeding 8 sols. The science possibilities of such a mission are very limited, but nevertheless useful.

3.3.1 Descent Science

The engineering sensors included in the EDL system have as main objective helping to achieve a safe landing. However, the data produced by these sensors can also provide important scientific results. For example, it will be possible to retrieve the atmospheric profile along the descent trajectory, and obtain fundamental constrains for updating and validating the Mars standard atmospheric model.

3.3.2 Environment Science

The opportunity exists to accommodate a few, simple sensors (requiring no deployment and limited electrical power and data return) and cameras on the EDL Demonstrator. Very useful measurements could be conducted over the 8-sol surface mission.

A small science payload will be selected in response to an open, competitive call.

4 DESCRIPTION OF THE EXOMARS MISSIONS

The objectives of the ExoMars Programme will be pursued as part of a broad cooperation with NASA having as long-term goal an international Mars sample return mission. Two missions are foreseen for the 2016 and 2018 launch opportunities to Mars.

4.1 Orbiter and Demonstration Lander Mission in 2016

ESA will design and build a large spacecraft, capable of carrying the ESA EDL Demonstrator and releasing it for landing (Fig. 7). Thereafter, the Orbiter will perform a nominal science mission of 2 years, followed by a proximity and deep space communications mission of at least 3 years. The communications portion of the Orbiter mission will support the 2018 rovers, as well as other future international landed assets.

NASA will launch the ESA spacecraft in early January 2016 on an Atlas V, Series 4, rocket, performing a direct injection onto a Mars T2 transfer trajectory. The spacecraft will arrive at Mars approximately 9 months later, in mid-October 2016. Prior to arrival, the EDL Demonstrator will be separated, entering the Martian atmosphere from the hyperbolic arrival trajectory.

The release of the EDL Demonstrator will take place 3 days prior to the Orbiter's Mars Orbit Insertion (MOI) manoeuvre. The Orbiter's capture manoeuvre will be designed to receive UHF radio beacon signals from the EDL Demonstrator as it performs its entry, descent, and landing. After capture, the ExoMars Orbiter will be in a 4-sol elliptical orbit. This orbit will be maintained until the EDL Demonstrator communications cease, following the depletion of its residual battery energy, presently estimated to be about 8 sols after landing. Once the EDL Demonstrator surface operations are complete, the Orbiter will begin a series of manoeuvres to change its orbit inclination to 74° and reduce the apoapsis using on-board fuel reserves. Further reductions of the apoapsis will be achieved by aerobraking, over a period of about 5 months, followed by a final circularisation manoeuvre to arrive at the 1-sol science and communications orbit, having an altitude of about 400 km.

The science operations phase is expected to begin in March 2017 and last two years. The 2018 mission will arrive to Mars during January 2019. Should other data relay satellites not be available, the emphasis on the Orbiter mission will then shift to rover surface communications support. The ExoMars Orbiter will include fuel to provide communications support and science operations until end 2022.

The EDL Demonstrator will allow Europe to master the technologies necessary to land on the surface of Mars with a controlled orientation and touchdown velocity. Its design maximises the use of technologies already in development within the ExoMars programme. These include:

- Thermal protection system material;
- Parachute system;
- Doppler radar altimeter;
- Liquid propulsion controlled final braking.

The configuration of the EDL Demonstrator will be developed with a view to permitting a scaling of the design for future landers. Engineering sensors will be included to assess the EDL performance. The Demonstrator will have a heat shield diameter of about 2.4 m and will be designed to survive a severe dust storm, since the lander will arrive during the global dust storm season. After entry, the system will deploy a single-stage disk-gap band parachute. The Demonstrator will complete its landing using a closed-loop control system based on a Doppler radar and Inertial Measurement Units (IMU) that will guide the operation of three clusters of pulsed-mode liquid thrusters.

The EDL Demonstrator is expected to survive on the surface of Mars for about 8 sols using excess capacity in the batteries. A set of scientific sensors will be embarked as a science demonstration, within the mass resources available in the EDL Demonstrator and without adding additional systems for solar power generation or for thermal control, such as Radioisotope Heater Units.

The 2016 mission is lead by ESA. Spacecraft operations, including EDL Demonstrator operations, will be performed by ESOC, in Darmstadt (D). NASA will manage the science operations of any NASA orbiter instruments, but commanding and telemetry monitoring of Orbiter instruments will be implemented by ESOC, through coordination with the NASA responsible groups. Science operations for the ESA EDL Demonstrator instruments will be managed by ESA. Programming of the timeline and telemetry monitoring of EDL Demonstrator instruments will be the responsibility of ESOC through coordination with the ESA responsible groups.

The proximity link communications operations (e.g. between Orbiter and Rovers) are possible through a NASA contribution of the Electra UHF transceiver for the ExoMars Orbiter. The transceiver operations will be the responsibility of ESOC. However, the maintenance and planning of proximity communications support for the multiple surface assets on Mars will be performed jointly with NASA.

Launcher Orbiter and EDL Demonstrator

Fig. 7: The 2016 mission is ESA-led. ESA will design and build a large Orbiter and an EDL Demonstrator. NASA will provide the launcher.

4.2 Rover Mission in 2018

The ESA ExoMars Rover, having a mass of approximately 300 kg, will be accommodated with a NASA Rover of similar size within a single Aeroshell (Fig. 8). NASA will launch the spacecraft in April 2018 on an Atlas V, Series 5, rocket, performing a direct injection onto a Mars T2 transfer trajectory. The spacecraft will arrive to Mars approximately 9 months later, in mid-January 2019. During the cruise phase, a Carrier spacecraft will support the Aeroshell and separate from it shortly before atmospheric entry —NASA furnishes both these elements. The Aeroshell will decelerate through the initial part of the atmosphere using its heat shield, followed by parachute descent, and finally, by a fully controlled descent and touchdown phase, using the so-called “sky crane” system. This system is derived from that used for the Mars Science Laboratory (MSL) mission planned for launch in 2011. The sky crane will lower the two rovers onto the surface of Mars on a common support platform. Once on the surface, the rovers will deploy their appendages, perform check out tests, and egress from the platform. Each rover will then proceed with its respective mission objectives. ESA’s ExoMars Orbiter, launched as part of the same cooperation with NASA in 2016, will support data relay communications for the rovers.

The 2018 mission is lead by NASA. Spacecraft operations will be performed by JPL, in California (USA), for all phases of the mission until touchdown. Once on the surface of Mars, NASA will control their Rover through commands transmitted by ESA's ExoMars Orbiter, or by other possibly available communication assets. The Rover Operations Control Centre (ROCC) in Turin (I) will control ESA's ExoMars Rover through commands transmitted by the ExoMars Orbiter or by other communication assets, if available.

Science operations for the ESA Pasteur instruments on the Rover will be managed by ESA in coordination with scientific groups. The Payload data will be first provided to the experiment teams for detailed scientific analysis. The final data will be archived at the European Space Astronomy Centre in Villafranca del Castillo (E).

The nominal mission of the ExoMars Rover lasts 180 sols (approximately 6 months).

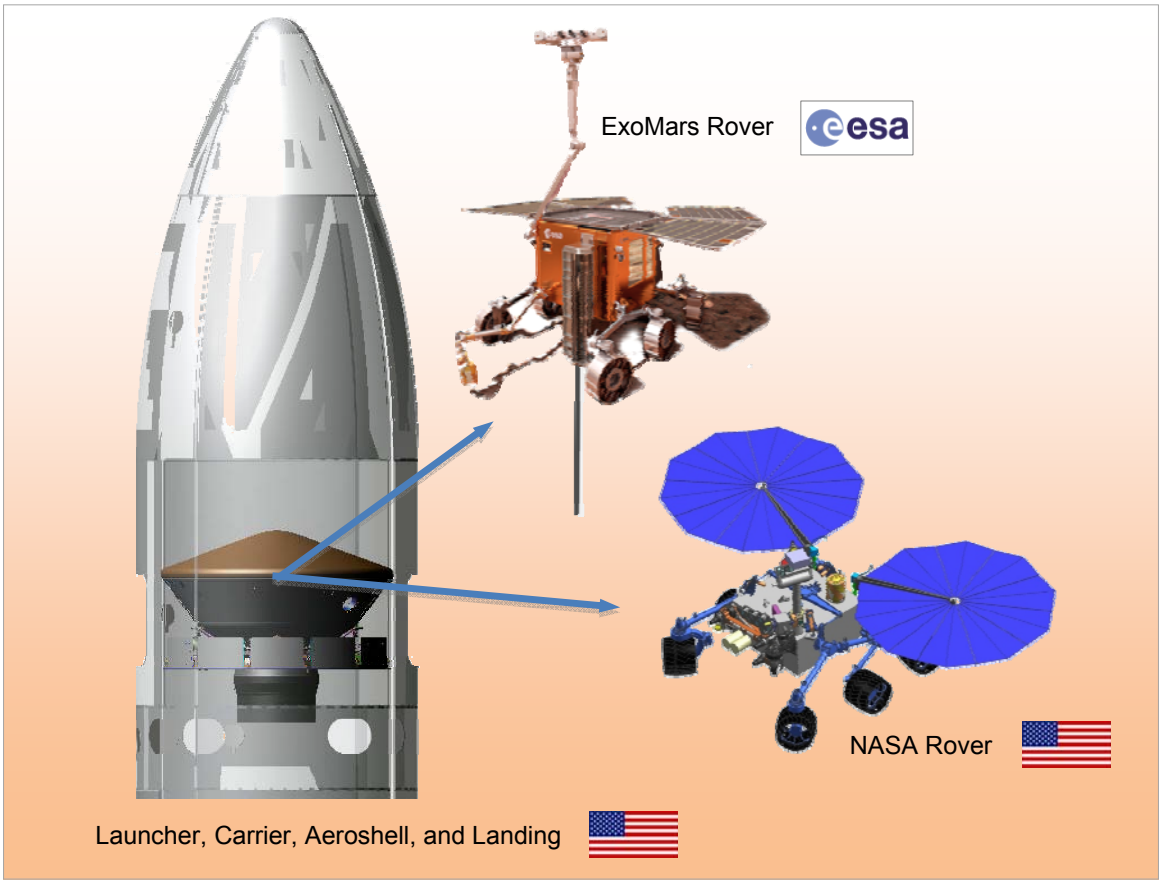

Fig. 8: The 2018 mission is NASA-led. NASA will launch the mission and provide the Carrier, the Aeroshell, and the sky crane landing system. The Aeroshell will accommodate ESA's ExoMars Rover and a NASA Rover of similar size.

5 PROGRAMME PARTICIPATION

5.1 Rover Payload Confirmation Process

The ExoMars Rover payload confirmation follows a process that is consistent with the commitments undertaken by ESA in [RD 1] , vis-à-vis the international scientific community and the Programme Board, for the scientific definition and implementation of the ExoMars Rover mission.

The ExoMars Rover instruments will be provided as "national contribution." This effort must be carefully coordinated since the Pasteur scientific proposals have an international composition; and in most cases the instruments are constructed using elements developed by research institutions in different countries. All parties (hereafter referred to as Instrument Partners) participating in the development of an instrument for the ExoMars Rover mission will be required to undersign an Instrument Multilateral Agreement (IMA). The management and responsibilities, including the role of funding agencies and Principal Investigators, are in agreement with those in other ESA scientific missions.

5.1.1 Rover Payload Review Evaluations

The Rover's instruments have so far undergone three independent, international peer assessments: The first one in response to the 2003 Call [RD 1] , a 2007 Payload Confirmation Review (PCR) [RD 2] , and the Payload Confirmation Review #2 (PCR2) in 2009. The latter two exercises became necessary due to changes in the mission scenario and in the resources available for the Pasteur payload.

The 2009 PCR2 panel identified five possible payload configurations addressing the Rover mission's scientific objectives, spanning the mass range 16.7 to 12.3 kg (called Options A–E respectively), with correspondingly decreasing science capabilities (please see [RD 3]). The panel also underlined the need to preserve the 2.0-m depth reach in the drill, for scientific and reliability reasons.

On the basis of the Rover mass that the 2016 mission configuration being considered at the time could accommodate, the ExoMars Project proposed to implement Option D. Option D includes seven instruments (PanCam, WISDOM, Ma_MISS, MicrOmega IR, Raman, MOMA, and MARS-XRD). The Programme Board (PB-HME) accepted this as a "minimum payload" and recommended to the project exploring possibilities to reinforce the exobiology content of the Rover mission.

Since the NASA-ESA 2018 mission scenario can afford the ExoMars Rover some mass and geometry advantages, the ExoMars Project has undertaken evaluating the possibility to accommodate additional instruments, in line with the PCR2 identified payload options.

The next payload option up, Option C, included the robotic arm. Among these instruments, the PCR2 panel judged the CLose-UP Imager (CLUPI) "essential for achieving the mission's scientific objectives." CLUPI can provide much needed, high-resolution imaging capabilities (20-µm resolution) to study the depositional environment, and potential morphological signatures of past biological activity preserved on the texture of surface rocks. This is a function that exceeds the possibilities of the PanCam camera system. Even if it proves impossible to implement the robotic arm, an alternative way to accommodate CLUPI would be desirable to reinforce the Rover's exobiology capabilities.

Another exobiology instrument considered by the PCR2 panel was the Life Marker Chip (LMC). LMC can perform liquid extraction of organic molecules from the sample material collected by the drill. LMC allows detecting simultaneously multiple molecular biomarkers and non-biogenic organic molecules employing specific antibodies in a microarray inhibition/competition immunoassay. The PCR2 review panel concluded that "the LMC concept provides a promising approach for astrobiology research, its aims are innovative, and the results could be fascinating." However, it also found that the instrument had not then reached a sufficient technology readiness level, particularly concerning the state of development of functional antibodies and their stability under mission conditions. The

PCR2 panel recommended that LMC be developed further and considered for a Mars mission after 2016. The postponement of the ExoMars Rover launch to 2018 has enabled LMC to be included in the Pasteur payload.

Summarising, nine instruments are selected for the ExoMars Rover mission: PanCam, CLUPI, WISDOM, Ma_MISS, MicrOmega IR, Raman, MARS-XRD, MOMA, and LMC.

5.1.2 Rover Payload Instrument Multilateral Agreement (IMA)

The purpose of the Instrument Multilateral Agreement is to record the commitment of the Instrument Partners, to define their respective rights and obligations, and to organise the management of the Instrument Projects.

The Instrument Partners agree to cooperate pursuant to the terms of the Instrument Multilateral Agreement in order to execute and fulfil the tasks necessary to design, develop, manufacture, and deliver to ESA specific instruments for integration in the ExoMars Rover mission.

The performance of the Instrument Projects is shared between the Instrument Partners according to the allocation of tasks agreed by the Instrument Partners with each instrument's Principal Investigator and Project Manager on the basis of the Partners' expertise, and of the resources made available by their funding institutions. The scientific and technical scope of the various Instrument Projects may be set out in an Annex.

In essence, all the elements conducive to the timely and satisfactory completion of the Instrument Projects are identified in the IMA, including the form and time of the commitments that the Partners agree to make available to the Project to provide their payload contribution. It will be ESA's responsibility to ensure the completeness and thoroughness of the information contained in the IMA prior to its signature by all instrument Lead Funding Agencies and ESA.

Any NASA payload contributions will be agreed and governed by the relevant ESA-NASA agreements.

Upon the successful signature of the IMA, ESA will present the whole dossier to its Advisory Bodies for review and endorsement, and to PB-HME for approval. This will complete the ExoMars Rover Payload Confirmation Process.

5.2 Orbiter Payload Confirmation Process

The ExoMars Orbiter instruments will be provided as "national contribution." This effort must be carefully coordinated since the scientific proposals will likely have an international composition; and in most cases the instruments will be constructed using elements developed by research institutions in different countries. All parties (hereafter referred to as Instrument Partners) participating in the development of an instrument for the ExoMars Orbiter mission will be required to undersign an Instrument Multilateral Agreement (IMA). However, any NASA payload contributions will be agreed and governed by the relevant ESA-NASA agreements.

5.2.1 Orbiter Payload Review Evaluation

An appropriate science payload will be selected in response to an open, competitive Announcement of Opportunity (AO) to be jointly organized by ESA and NASA. As for the ExoMars Rover mission, an independent, international peer review panel will evaluate the instrument proposals received in response to the call.

5.2.1.1 Evaluation Criteria

The peer review panel will evaluate each instrument proposal using the following preliminary criteria:

- Relevance of the instrument proposal's scientific goals to the mission's scientific objectives: To study Martian atmospheric trace gases and their sources.
- Adequacy of the instrument measurements to address the mission's objectives.

- Likelihood of the instrument to provide the required measurement performance.
- Feasibility and heritage of the proposed implementation.
- Instrument development status.
- Availability of technologies required by the instrument. In case new technologies are required, assessment of their development status.
- Identification and justification of any ESA hardware or software contribution to the instrument.
- Compliance with the spacecraft interfaces.
- Credibility of the instrument's development plan and test and validation programme.
- Compatibility of the instrument with the Mars orbital environment, mission constraints, and spacecraft resources.
- Assessment of the instrument's operational complexity.
- Quality of the data analysis plan.
- Adequacy of the management plan in relation to the instrument's complexity, both technical and/or arising from managing element/institution interfaces within the instrument consortium.
- Assessment of compliance with applicable planetary protection rules.
- Continuity of human and institutional resources to ensure a timely execution of the instrument project, including development, construction, calibration, operation, data analysis and publication, and provision of results to the Agency science archives. ESA and NASA will undertake the analysis of manpower funding profiles for all mission phases; including science exploitation, publication, and archiving; for each science institute within the instrument consortium, verifying that they are covered by the appropriate funding agency and confirmed by the instrument's Lead Funding Agency.
- Competence and experience of the instrument team in all relevant areas (science, technology, software, management, etc.).
- Credibility of resource requirements estimates (mass, power, data volume, etc.).
- Credibility of costing. ESA or NASA staff experienced in instrument cost analysis will perform this evaluation in coordination with the instrument's Lead Funding Agency.
- Compliance with the ESA applicable management, engineering, reporting, and product assurance requirements.
- Possible financial impact of the proposed instrument on ESA.
- Verification of the commitment of all national funding agencies to adequately support member institutes within the instrument consortium under the overall responsibility of the Lead Funding Agency.
- Commitment of the Principal Investigator's funding agency to become the Lead Funding Agency.

5.2.1.2 Selection Process

Scientific Evaluation:

An independent, international peer review panel organised by ESA and NASA will evaluate the scientific merits of each instrument proposal and its relevance to the mission objectives.

Technical, Managerial, and Financial Evaluation:

A review panel, supported by ESA and NASA staff, will form a technical review team to assess all instrument proposals' managerial and technical compliance with the mission requirements. The proposed funding scheme will be also scrutinised.

Payload/Spacecraft Compatibility:

The ExoMars Project will establish a technical and managerial panel to assess the compliance of instrument proposals to the Orbiter accommodation requirements.

Final Recommendation

Based on the technical and scientific assessment of each instrument proposal and the Orbiter accommodation assessment, the peer review panel will recommend a configuration for the ExoMars Orbiter payload that satisfies the mission's scientific objectives within the available resource envelope.

The panel-recommended payload will become the new reference payload to be studied by the ExoMars Project and Industry. ESA will present the reference payload to the Advisory Bodies for endorsement, and to the Programme Board (PB-HME) for approval.

5.2.2 Orbiter Payload Instrument Multilateral Agreement (IMA)

The purpose of the Instrument Multilateral Agreement is to record the commitment of the Instrument Partners, to define their respective rights and obligations, and to organise the management of the Instrument Projects.

The Instrument Partners agree to cooperate pursuant to the terms of the Instrument Multilateral Agreement in order to execute and fulfil the tasks necessary to design, develop, manufacture, and deliver to ESA specific instruments for integration in the ExoMars Orbiter mission.

The performance of the Instrument Projects is shared between the Instrument Partners according to the allocation of tasks agreed by the Instrument Partners with each instrument's Principal Investigator and Project Manager on the basis of the Partners' expertise, and of the resources made available by their funding institutions. The scientific and technical scope of the various Instrument Projects may be set out in an Annex.

In essence, all the elements conducive to the timely and satisfactory completion of the Instrument Projects are identified in the IMA, including the form and time of the commitments that the Partners agree to make available to the Project to provide their payload contribution. It will be ESA's responsibility to ensure the completeness and thoroughness of the information contained in the IMA prior to its signature by all instrument Lead Funding Agencies and ESA.

Any NASA payload contributions will be agreed and governed by the relevant ESA-NASA agreements.

Upon the successful signature of the IMA, ESA will present the whole dossier to its Advisory Bodies for review and endorsement, and to PB-HME for approval. This will complete the ExoMars Orbiter Payload Confirmation Process.

5.3 EDL Demonstrator Payload Confirmation Process

The EDL demonstrator constitutes a technological development rather than a science platform. The nature of the sensors that it can accommodate is relatively simple, and will only be able to operate for a few sols on the Martian surface. ESA will consider implementing an integrated payload if it provides efficiency in the utilisation of resources and reduces implementation risks. ESA will try to streamline as much as possible the payload definition process.

5.3.1 EDL Demonstrator Payload Review Evaluation

A modest science payload will be selected in response to an open, competitive ESA call. An independent, international peer review panel will evaluate the proposals received.

5.3.2 EDL Demonstrator Payload Instrument Multilateral Agreement (IMA)

The purpose of the Instrument Multilateral Agreement is to record the commitment of the Payload Partners, to define their respective rights and obligations, and to organise the management of the Payload Project.

The Payload Partners agree to cooperate pursuant to the terms of the Instrument Multilateral Agreement in order to execute and fulfil the tasks necessary to design, develop, manufacture, and deliver to ESA a payload for integration in the ExoMars EDL Demonstrator.

The performance of the Payload Project is shared between the Payload Partners according to the allocation of tasks agreed by the Payload Partners with each instrument's Principal Investigator and Project Manager on the basis of the Partners' expertise, and of the resources made available by their funding institutions. The scientific and technical scope of the Payload Project may be set out in an Annex.

In essence, all the elements conducive to the timely and satisfactory completion of the Payload Project are identified in the IMA, including the form and time of the commitments that the Partners agree to make available to the Project to provide their payload contribution. It will be ESA's responsibility to ensure the completeness and thoroughness of the information contained in the IMA prior to its signature by the Payload Lead Funding Agency and ESA.

Upon the successful signature of the IMA, ESA will present the whole dossier to its Advisory Bodies for review and endorsement, and to PB-HME for approval. This will complete the ExoMars EDL Demonstrator Payload Confirmation Process.

5.4 Instrument Deselection Policy

The following Deselection Policy will apply for the entire implementation phase of ExoMars programme missions following the completion of the relevant payload confirmation process. The reasons that could lead to the deselection of an instrument are:

1. Resource insufficiency: For example, available mass for instruments. This possibility may arise as a result of a more-accurate technical estimate performed by Industry. In such cases, ESA will endeavour to define alternatives that may solve the problem whilst minimising the consequences for the mission's science return. In case a satisfactory solution cannot be found at project level, ESA will organise a dedicated ExoMars Science Working Team (ESWT) meeting to consider the situation for the payload as a whole. All major payload decisions will be taken in consultation with the ExoMars science community and ESA's Advisory Bodies (as independent reviewers).

2. Instrument exceeds allocated resources: For example, an instrument's mass is greater than that agreed. This is considered a grave problem. The Instrument Project has the obligation to inform ESA early of any such instances; ESA will do its outmost to assist them in the search for a viable solution. In case this is not possible, ESA will evaluate the risk to the mission and may recommend deselecting the instrument. The decision leading to this recommendation will be taken in consultation with the ExoMars science community and ESA's Advisory Bodies.

3. Instrument funding insufficiency: At the time of signature of the IMA, all Instrument Partners commit to timely provide the necessary resources to bring the Instrument Project to a successful completion. In case a funding agency were to break its contract, for whatever reason, the following mechanism will be put in effect:

    a. Evaluation of the effect of deselecting the instrument by ESA in consultation with its Advisory Bodies.

    b. Discussions at PB-HME on the possibility that another country may take up the commitment. If this proves feasible, the instrument will be retained; otherwise ESA will recommend that the instrument be deselected.

    c. In case the Lead Funding Agency does not have the financial capability to comply with its IMA commitments, ESA will recommend that the instrument be deselected.

4. Likelihood that instrument may not be available in time: ESA will closely monitor the progress of all ExoMars Instrument Projects. In case substantial delays were to occur, they would constitute a breach of the commitments undertaken in the IMA. If the Agency judges that the delays put at risk the mission launch date, ESA will recommend that the instrument be deselected.

5. Instrument technical or scientific underperformance: All instruments must be able to timely and reliably demonstrate appropriate technical and scientific performance to be included in the mission. If ever underperformance problems were to occur, the Instrument Project has the obligation to inform ESA early of such instances. ESA will do its outmost to assist them in the search for a viable solution. In case this is not possible, ESA will evaluate the risk to the mission —programmatic, technical, and scientific— and may recommend deselecting the instrument. The decision leading to this recommendation will be taken in consultation with the ExoMars science community and ESA's Advisory Bodies.

The final decision for deselecting an instrument will be taken by the Programme Board (PB-HME), based on the recommendations of ESA and its Advisory Bodies. ESA will make every effort possible to ensure that the scientists affected by such an occurrence find a place in other instrument teams.

5.5 Modes of Participation

5.5.1 Rover Modes of Participation

The ExoMars Rover mission is open to investigators from all countries. Due to the highly integrated nature of the Rover's Pasteur payload, instrument Principal Investigators have to be based in an ESA member state participating in the Aurora Programme*. Each instrument team must also designate a Co-Principal Investigator, to assist the Principal Investigator and to represent the science team. The Co-Principal Investigator is preferably from a different country than the Principal Investigator. The Co-Principal Investigator can be from a non-ESA country.

The possible modes of participation to the ExoMars Rover mission are:

1. Principal Investigator (PI): The scientist that coordinates and represents a team providing an instrument. He/she is the main point of contact for ESA and the ExoMars Rover industrial consortium.
2. Co-Principal Investigator (Co-PI): Assists the Principal Investigator and also represents the instrument team. A Co-PI appointment recognises a major instrument development carried out in a country/institution different from that of the PI. A Co-PI has similar rights to the PI, but the PI constitutes the formal interface to the ExoMars project.
3. Co-Investigator (Co-I): A member of an instrument team providing an instrument.
4. Interdisciplinary Scientist (IDS): An expert in specific scientific subjects in support of the multidisciplinary nature of the ExoMars Rover mission.
5. Guest Investigator (GI): A scientist participating in the data collection and analysis of one or more instruments.

This nomenclature aligns the ExoMars Rover modes of participation with those used in ESA's Science Programme and in NASA. Previous Rover Pasteur payload Team Coordinators (TC), Deputy Team Coordinators (DTC), and Team Members will henceforth be considered PIs, Co-PIs, and Co-Is respectively.

5.5.2 Orbiter Modes of Participation

The ExoMars Orbiter mission is open to investigators from all countries. Principal Investigators have to be based either in an ESA member state participating in the Aurora Programme or in the United States. Each instrument team must also designate a Co-Principal Investigator, to assist the Principal Investigator and to represent the science team. The Co-Principal Investigator is preferably from a different country than the Principal Investigator.

The possible modes of participation to the ExoMars Orbiter mission are:

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* Countries presently subscribing the Aurora Programme are: Austria, Belgium, Canada, Denmark, France, Greece, Germany, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

1. Principal Investigator (PI): The scientist that coordinates and represents a team providing an instrument. He/she is the main point of contact for ESA and the ExoMars Orbiter industrial consortium.
2. Co-Principal Investigator (Co-PI): Assists the Principal Investigator and also represents the instrument team. A Co-PI appointment recognises a major instrument development carried out in a country/institution different from that of the PI. A Co-PI has similar rights to the PI, but the PI constitutes the formal interface to the ExoMars project.
3. Co-Investigator (Co-I): A member of an instrument team providing an instrument.
4. Interdisciplinary Scientist (IDS): An expert in specific scientific subjects in support of the multidisciplinary nature of the ExoMars Orbiter mission.
5. Guest Investigator (GI): A scientist participating in the data collection and analysis of one or more instruments.

5.5.3 EDL Demonstrator Modes of Participation

Because this mission element constitutes a technological development rather than a science platform, the nature of the sensors that can be embarked is relatively simple. ESA will consider implementing an integrated payload if it provides efficiency in the utilisation of resources and reduces implementation risks. Instrument Principal Investigators have to be based either in an ESA member state participating in the Aurora Programme or in the United States.

The possible modes of participation to the ExoMars EDL Demonstrator mission are:

1. Payload Leader (PL): The scientist that coordinates and represents a team providing an integrated payload. He/she is the main point of contact for ESA and the ExoMars EDL Demonstrator industrial consortium for the integrated payload. The PL has PI status for the integrated payload.
2. Principal Investigator (PI): The scientist that coordinates and represents a team providing an instrument. He/she is the main point of contact for ESA and the ExoMars EDL Demonstrator industrial consortium for the specific instrument.
3. Co-Investigator (Co-I): A member of an instrument team providing an instrument or payload element.

5.5.4 Principal Investigator

An instrument team's Principal Investigator will have the following duties:

1. Represent, together with the Co-Principal Investigator, the instrument team; and be the ultimate responsible person, with respect to ESA and the ExoMars industrial consortium, for all matters concerning the instrument's science definition, development, performance, and operations.

2. Management:
   a. In cooperation with the Co-Principal Investigator, organise the planned commitments and contributions from all Instrument Parties with a view to a prompt signature of the Instrument Multilateral Agreement.
   b. In cooperation with the Co-Principal Investigator, organise the efforts, assign tasks, and guide the instrument consortium.
   c. In cooperation with the Instrument Project Manager (appointed by the instrument team) and the Co-Principal Investigator, establish an effective management scheme to be used for all aspects of the instrument project, technical and scientific.
   d. In cooperation with the Instrument Project Manager and the Co-Principal Investigator, ensure that the instrument project's schedule is respected.

e. In cooperation with the Instrument Project Manager and the Co-Principal Investigator, timely report to the ExoMars project team the status of all instrument project activities.

f. In cooperation with the Instrument Project Manager and the Co-Principal Investigator, support ESA management requirements (e.g. investigations, progress reviews, change procedures, product assurance, planetary protection, etc.), as detailed in the instrument E-ICD.

3. Science:

a. Assume a full and active role in the instrument's science definition and development.

b. Maintain, at all times, a constructive and positive spirit within the instrument science team, and vis-à-vis other instrument teams.

c. Seek a fruitful cooperation with all instrument teams, openly sharing information, with the goal to maximise the programme's science return.

d. In case of problems or conflicts, seek ESA's mediation to try to resolve them quickly, in a manner that is just and fair to all involved parties.

e. Monitor the compliance of the instrument's design with the scientific requirements contained in the "Scientific Payload Requirements Document."

f. Monitor the compliance of the instrument's design with the interface requirements in the respective E-ICD.

g. When so requested, attend meetings of the Science Working Team, Advisory Bodies, and Industry —as appropriate— to support mission definition activities.

h. Ensure the scientific relevance and robustness of the instrument's results. This includes, *inter alia,* adequate verification and calibration of all instrument parts and elements, both on the ground and later in space; timely and thorough testing of the instrument's science using representative natural samples in mission-relevant conditions; etc.

i. Provide regularly to ESA progress reports on instrument development status, scientific verification, laboratory and field test results, etc.

j. Actively and regularly inform the scientific community at large —in meetings and publications— of progress in the instrument's definition, its science, and its intended use in the ExoMars missions.

k. Support the utilisation of the instrument's science by fellow scientists:

- Provide a complete instrument "Technical and Science User Manual" in Word format. This document will be made available by ESA for download once the data are made public.
- Provide ESA with all calibration information necessary to allow others to effectively use the instrument's data;
- Provide simulated data streams to test the correct functioning of the data distribution and analysis service;
- Timely provide all mission science data (raw data, calibrated data, and higher-level data), including all necessary calibration products and software, to the ExoMars archive in a format that will be agreed by ESA and the ExoMars missions' science community.

l. Participate to the definition of the science operations and data handling service.

m. Support the Science Operations Centre (SOC) and the Rover Operations Centre (ROC).

n. Support the real time verification and analysis of the instrument science results to assist with the ExoMars mission planning activities and surface operations.

o. In coordination with all other Rover, Orbiter, and/or EDL Demonstrator scientists, exploit the ExoMars missions' scientific results in an effective manner; and ensure their publication as soon as possible —in accordance with the ExoMars publication rules.

p. Support the reporting, by ESA on the web, of the ExoMars missions' science activities and results.

4. Hardware:

a. Coordinate the definition of the instrument's functional requirements, and of those of its auxiliary equipment (e.g. MGSE, EGSE, etc.).

b. Ensure the overall development, construction, testing and delivery of the instrument, in accordance with the technical and programmatic requirements defined by ESA.

c. Manage and update the evolution of all instrument interfaces, ensuring that they are accurately reflected in the relevant E-ICD.

d. Ensure that the development, construction, testing, and delivery of the instrument are appropriate to the objectives and lifetime of the mission, and to the environmental and interface constraints under which it must operate.

e. Deliver adequate instrument verification models (EQM, STM, etc.) to the ExoMars industrial consortium, as required to verify system interfaces. What exactly is required is defined in the applicable E-IRD.

f. Deliver an instrument Flight Model (FM) and Flight Spares, in accordance with the technical requirements defined in the applicable E-IRD.

g. Support the system-level integration and test activities related to, or involving, the instrument.

h. Provide all necessary equipment necessary to process and interpret the instrument data, as agreed with ESA, and defined in the applicable E-IRD.

i. Ensure that all instrument hardware and software is compliant with ESA requirements, through participation in technical working teams and control boards (i.e. for organic cleanliness), as requested.

j. Ensure that the mission's system level performance (technical and scientific) can be maintained, and is in no way impeded or compromised by any instrument-related factors, either due to instrument team's actions or omissions.

k. Timely deliver to ESA all required instrument project documentation, as defined in the applicable E-IRD.

5. Software:

a. Ensure the timely development, testing, and documenting of all software necessary, in accordance with the rules and guidelines stipulated in the E-IRD.

b. Specify and support the development, testing, and documenting of all software required for the verification, operation, and data reduction/analysis of all instrument parts or elements, including those built or provided under ESA responsibility, in accordance with the rules and guidelines stipulated in the E-IRD.

c. Ensure the timely delivery to ESA of any instrument-specific software needed for instrument testing or operation in accordance with ESA-approved guidelines, procedures, and schedules. This includes any software required by the ROCC, as specified in the Science Operations Requirements document.

d. Maintain and update all instrument software and documentation until the end of the mission.

6. Product Assurance:

a. Provide a Product Assurance function within the instrument project in compliance with the applicable E-IRD requirements.

7. Planetary Protection:

a. Provide a Planetary Protection function within the instrument project in compliance with the applicable E-IRD requirements.

8. Operations:

a. Provide support for the preparation and implementation of the ExoMars mission operations, up to the end of the mission, in compliance with the applicable E-IRD requirements. This will likely imply being physically present (at least during the first few months) at the ROCC to assist with Rover science operations.

9. Financial:

   Financial support for the Principal Investigator and his/her immediate collaborators will have to be guaranteed by the instrument's Lead Funding Agency. The Lead Funding Agency will also be considered responsible vis-à-vis ESA and the Programme Board (PB-HME) for the coordination of all financial matters related to the specific instrument, including, but not limited to, the procurement of instrument contributions in the form of elements, parts, software, or support from institutes in other countries. All Team Members are required to seek agreement with the instrument's Lead Funding Agency. The successful agreement between all Instrument Partners is formalised in the Instrument Multilateral Agreement (IMA). The signature of the IMA by all Instrument Partners is a prerequisite for the confirmation of the instrument in the ExoMars missions. Thereafter, the Lead Funding Agency becomes ESA's sole point of contact for all financial matters concerning the specific instrument project. The Lead Funding Agency has the overall financial responsibility for the instrument project's success.

   In case the Principal Investigator, for any reason and at any time in the project, must withdraw or resign from his role, the appointment of a new Principal Investigator to the instrument project shall be carried out by the Team Members, submitted to the approval of the Lead Funding Agency, on the basis of the most qualified person to bring the project to a satisfactory completion. In a case where the nationality of the Principal Investigator was to change, it would be normal for the Lead Funding Agency to change as well; however, this would need to be assessed on a case-by-case basis, depending on the particular circumstances. The Lead Funding Agency is expected to honour its funding commitments, according to what is recorded in the IMA.

10. Communications and Public Outreach:

    a. Support ESA science communication and public outreach activities for the ExoMars missions.

It is expected that the instrument Principal Investigator may wish to delegate or share the execution of some of these tasks with either the Instrument Project Manager or the Co-Principal Investigator. The PI remains, in any case, the person ultimately responsible for the activities listed here. The PI will promptly inform ESA and the Lead Funding Agency of any changes in the organisation or composition of the instrument project team from what is indicated in the IMA.

Instrument Project Manager

The Instrument Project Manager (IPM) is a very important figure within an instrument team's organisation. Under the authority of the PI, and reporting to both PI and Co-PI, the IPM will be in charge of the day-to-day planning and execution of the instrument project.

5.5.5 Co-Principal Investigator

The Co-Principal Investigator assists the Principal Investigator, and represents him/her when he/she is not available; therefore the duties applicable to the role of PI are also valid for that of Co-PI. The PI and Co-PI work together to bring the instrument project to a successful conclusion. The Co-PI must therefore also have a strong scientific background and good organisational skills. The day-to-day running of the instrument project is the responsibility of the Instrument Project Manager.

All ESA communications to the instrument Team Members are addressed to both the PI and Co-PI.

5.5.6 Co-Investigators

The experts forming part of a science team providing an instrument are Co-Investigators. Each Co-Investigator must have a well-defined role with regard to the contribution of hardware, software, scientific support, or expertise within the instrument consortium. These roles and qualifications will be identified and recorded in the relevant E-ICD. Team members may review the status of the team's composition regularly and implement changes if required. Any modifications will be promptly communicated to ESA and to the instrument's Lead Funding Agency. The Lead Funding Agency, however, will not change during the development of the instrument.

Co-Investigators are responsible for obtaining their own funding, which must be guaranteed by their respective national funding agencies, and which is formally underwritten with the Lead Funding Agency (holding overall financial responsibility with respect to the instrument development and its delivery to ESA) in the Instrument Multilateral Agreement (IMA).

5.5.7 Interdisciplinary Scientists

To ensure a solid, top-level science oversight, a number of Interdisciplinary Scientists (IDS) will be selected through an Announcement of Opportunity (AO) once the final configuration and the payload composition of each mission are well consolidated. These IDS appointments will not address instrument specific domains, but cover overarching science themes.

IDS proposals can be from international, multidisciplinary teams or from individual scientists. For example, for the ExoMars Rover, the IDS AO will request well-thought proposals seeking to use the Rover and Pasteur payload in an integral manner, i.e. not the singular instruments, but utilise the whole potential of the facility to answer scientific questions related to the mission's objectives. This AO will also constitute an opportunity to further consolidate the present scientific teams and their research objectives. Interdisciplinary science teams will therefore take part in the analysis of data from different instruments on board one or more elements of a mission.

The proposals submitted by Interdisciplinary Scientists will be structured in a manner similar to those already submitted in response to other ExoMars calls. The investigators must present clearly their scientific case, the relevance of their contribution to the overall mission science, and the instrument data sets needed to carry out their research programme. The proposals must also demonstrate the financial endorsement of the respective national funding agencies. The proposals' PI and Co-PI are also expected to provide support to the science communications activities of ESA and to the instrument teams.

Interdisciplinary Scientists will have the same obligations and privileges as other team members. In particular, they will have the same access and data rights as investigators supporting the development of ExoMars instruments.

5.5.8 Guest Investigators

Guest Investigators are individual scientists wishing to make use of the data collected by one or more instrument. Their proposal must be submitted to the instrument's PI and Co-PI, with a copy to the ESA Project Scientist. Their task has to be agreed with the instrument team, with the concurrence of the ESA Project Scientist. Guest Investigators may be appointed after launch.

6 SCIENCE MANAGEMENT

6.1 The Project Scientist

ESA nominates the ExoMars Project Scientist (PS). The PS is located at ESTEC, within the SRE directorate structure, and works in close cooperation with the ExoMars Project Manager (PM), in accordance with ESA's normal practice in the Science Programme. The PS is responsible for the mission's overall scientific coordination, and is the Agency's interface with the ExoMars science community.

The PS will organise all Announcements of Opportunity and Calls for instruments and investigations to be performed in the ExoMars mission, independent scientific peer reviews, and science consultation meetings with investigators. The ExoMars Project Scientist will chair the ExoMars Science Working Team (ESWT), and coordinate its activities (the role of the ESWT is described in the next section).

During all mission phases, from the beginning of the implementation phase until the end of the exploitation phase, the PS will be responsible for all scientific issues within the Project. The PS will advise the PM on technical matters affecting the missions' scientific performance. In particular, the PS will participate to the critical analysis of hardware design, performance, and operations with the objective to verify that the missions' scientific objectives can be fulfilled.

The PS will coordinate the scientific community's participation and support to milestone reviews during the project development phase. The PS will organise meetings with the scientific community to assist on project development issues that may impact the missions' science return; for example, in case a reductions of the instrument mass is necessary. The PS, in cooperation with the ESWT, may also establish *ad hoc* working teams to address specific mission aspects requiring consultation with the scientific community; for example, to propose a list of candidate landing sites and to participate in the down selection process.

The PS will coordinate the ExoMars Rover science operations with the Rover Operations Manager, under the PM responsibility. The PS will organise and be part of the science team supporting the (almost) real-time data evaluation and analysis capability necessary to effectively plan and conduct Rover surface operations. Likewise, the PS will participate to the definition of Orbiter payload operations with the objective to optimise the overall science return.

The PS will ensure an orderly, prompt, and fair implementation of the mission's data exploitation phase, will encourage the creation of multidisciplinary science teams to thoroughly analyse instrument results, and will foster the utilisation of the Rover and Orbiter payloads in an integral and holistic manner, facilitating the cooperation among scientists, all with a view to maximising the mission's science return and to promptly publish its results.

The PS will support the definition of agreements that may be important for the missions' scientific outcome; for example data-sharing agreements, inter-agency instrument cooperation agreements, etc.

The PS will regularly inform the international scientific community of ExoMars scientific, programmatic, and mission-development progress via Newsletters, web sites, press releases, brochures, etc. The PS will also contribute to ESA's reporting, to PB-HME and Advisory Bodies, on scientific aspects of ExoMars missions.

6.2 The ExoMars Science Working Team and its Structure

The ExoMars Science Working Team (ESWT) includes the PIs and Co-PIs of the instrument teams, and the PIs and Co-PIs of interdisciplinary science teams, once selected. However, the various teams may propose alternative members in case they consider this more appropriate. Additional participants may be invited to join at the ESWT's discretion. This advisory body will exist throughout the mission's lifetime.

The function of the ESWT will be to contribute to the science definition of the ExoMars Programme; to review ESA's project activities; and whenever it deems necessary, to make specific recommendations to the PM. Science working teams like the ESWT can prove very effective to ensure that the science focus of a complex programme like ExoMars remains ESA's foremost priority. The ESWT is chaired by the ExoMars PS.

The ESWT will monitor and advice ESA on all aspects of ExoMars missions that may have an effect on their scientific performance. The ESWT will assist the PS to maximise the ExoMars missions' scientific return within the established project and operations boundary conditions. It will advice the PS on matters concerning inter-agency science coordination, and will act as a focus for the interests of the international scientific community on ExoMars.

The ESWT represents all other Team Members and has a great responsibility towards the scientific community. The ESWT will work in a spirit of cooperation and openness, and will have the overall scientific success of ExoMars as its overarching objective. The ESWT will ensure the correct and transparent scientific conduct of its members, and will have the power to reprimand or, in extreme cases, recommend the removal of someone considered to have repeatedly acted against the interest of a mission's science.

The ESWT will aim to make decisions based on consensus, but if ever voting were to become necessary, each PI will have one vote, with the PS having a decisive vote in case of equal number of votes.

In order to increase the ESWT's working efficiency, science working subteams will be created for each ExoMars science element: Rover (RoverWT), Orbiter (OrbiterWT), and EDL Demonstrator (DemoWT). An ESA Science Coordinator (SC), reporting to the PS, will chair each of these WTs —the same person may fulfil "Project Scientist" and "Science Coordinator" functions. The WTs will have the very important task to support the detailed technical implementation of the scientific aspects of the mission. They will do this by participating in technical reviews (when so requested by the PS and the PM), and by monitoring the verification and testing of mission science elements and functions, whether under the responsibility of ESA or of any of the agencies or institutes participating in the ExoMars programme. At least three members of each WT will serve also in the ESWT; additional members will be appointed by the EWST on the basis of the specific activities to be undertaken. The three WTs will report their findings and recommendations to the ESWT (please see Fig. 9).

The participation of scientists to activities on several subteams is possible and even encouraged. The PS team, through ESWT meetings, will ensure the coordination between all subteams.

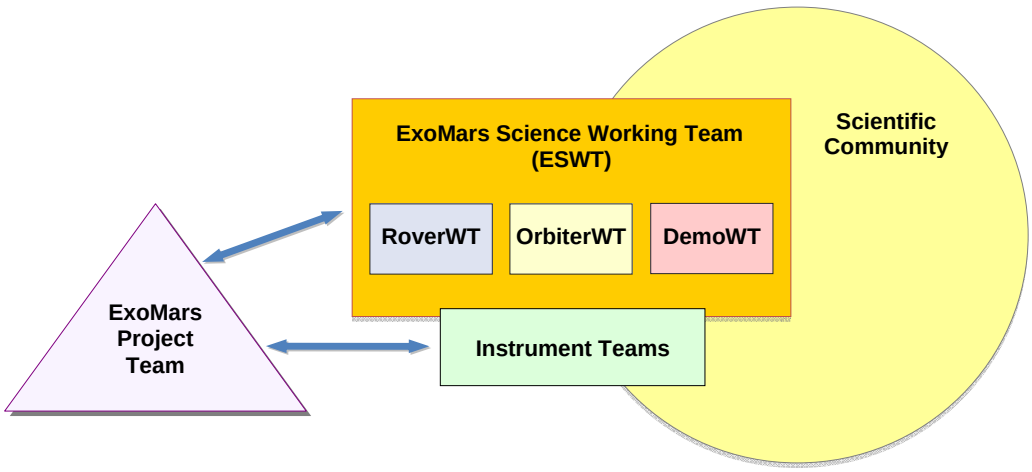

Fig. 9: The ExoMars Science Working Team (ESWT) advises ESA on all aspects of ExoMars missions that may have an effect on their scientific performance. The ESWT represents all instruments' Team Members and includes a small subteam for each ExoMars science element: Rover, Orbiter, and Demonstration Lander.

ESA will endeavour to minimise the cost of Working Team meetings by trying to coordinate, as much as possible, their timing with that of major international science conferences or reviews at ESTEC. All ESWT members are expected to rely on their own funding to participate in ESWT meetings.

More specifically, the ESWT will:

- Advice ESA on all scientific aspects of the development and operation of the ExoMars missions.
- Contribute to establishing a baseline operations scenario to fulfil the ExoMars missions' scientific objectives (see Chapter 3).
- Participate in major ExoMars project reviews, or as requested by the PS and PM.
- Perform specific tasks, as needed, during the development of the project.

The ESWT will review the tasks and activities of the Rover Operations Control Centre (ROCC) and of the Orbiter Science Operations Centre (SOC) to:

- Optimise the ExoMars missions' science return from a science operations point of view.
- Advise on the development of the science ground segment, with particular emphasis on the Rover and Pasteur payload operations scenario, software, ancillary data products, and the Pasteur science database and archive.

6.3 The Project Team

ESA will establish an ExoMars Project Team at ESTEC, within the SRE directorate structure. The Project Team may include project-integrated personnel from other ESA directorates. The Project Team will be responsible for the mission design and implementation. The ExoMars Project Manager (PM) heads the Project Team and is responsible for the full development and implementation of the missions. The PM will fulfil this function until the completion of the Orbiter and Rover commissioning phase, respectively.

Following the completion of the Orbiter commissioning phase, the Orbiter Mission Manager (MM) will assume the responsibility for the science exploration phase of the ExoMars Orbiter. Similarly, upon completion of the Rover commissioning phase, the Rover MM will become responsible for the Rover's surface science phase. The composition of the ExoMars Project Team may be revised according to the new tasks to be performed, and will include a science operations team, and a mission operations team.

ESA, via the Project Manager and the Mission Manager will retain the overall responsibility for the ExoMars programme, including all its elements, through all phases.

6.4 Monitoring of Instruments Development

The ESA Project Team, in close cooperation with the PS Team, will monitor the progress of the design, development, and verification of instruments provided by ESA participating states. For NASA instruments, the ESA Project Team will monitor the interface compliance and general programmatic issues only. The instrument teams will have to demonstrate to ESA, in regular reports and during formal reviews, compliance with the ExoMars scientific objectives, the applicable spacecraft system constraints, the spacecraft interfaces, and the programme's schedule, as defined in the mutually agreed instrument E-ICDs. Failure to timely or satisfactorily achieve this may result in the eventual deselection of an element, according to the rules defined in Sec. 5.4.

The ESA Project Team is not responsible for supporting the development of tools/services in the instrument teams' institutes for conducting scientific analysis of their instrument's data.

6.5 Selection of Landing Sites

6.5.1 Rover Landing Site

The 2018 mission will deliver two rovers to the surface of Mars: the ExoMars Rover and a NASA Rover. The scientific success of both rovers depends on being able to land safely on a scientifically interesting location.

The safety requirements for the landing site are often referred to as *landing site engineering constraints*; and to a large extent, are a consequence of the choice of Entry, Descent, and Landing (EDL) strategy —e.g. airbags, rocket-powered descent, etc. A candidate landing site's scientific interest, on the other hand, is determined by its geological conformation, which, in most cases, can only be assessed on the basis of imaging and spectroscopic data obtained from orbiting spacecraft.

Engineering constraints important to the selection of landing sites include: latitude and time of the year, for electrical power generation with solar arrays; elevation, for sufficient atmosphere to slow the descent; low horizontal wind speed, shear, and turbulence in the last few kilometres to minimise horizontal velocity at touchdown; low to moderate rock abundance; and a radar-reflective, load bearing surface that is not dominated by fine-grained dust and is thus safe for Rover traverse operations. To select candidate landing sites, engineering constraints must be addressed through the comprehensive evaluation of surface and atmospheric characteristics derived from existing remote sensing data and models, as well as from especially targeted orbital information.

The scientific evaluation of candidate sites will require the detailed examination of subtle morphological clues (e.g. putative water-related structures), topographic data indicating depressions where water could have accumulated, and spectroscopic signatures associated with evaporites and hydrothermal minerals.

Although a large variety of landforms on Mars provide evidence for the former flow of water, the general interpretation is that most of the more visible examples were formed by short-lived, intense outbursts (such as outflow channels stemming from catastrophic flooding events). However, fast-running surface water environments do not favour the formation of the fine-grained, sedimentary deposits and aqueous minerals known to best preserve organic substances.

In this regard, recent findings provide important evidence for the past existence of long-lasting, wet environments on Mars. In 2004, at its landing site in Meridiani Planum, the Opportunity Rover found the surface to be littered with smooth, hematite-rich spherules commonly known as "blueberries." These blueberries are several millimetres in diameter, and form when hematite chemically precipitates from iron-bearing fluids. These, and other analysed rocks, point to episodic inundation events by shallow surface water; followed by evaporation, exposure and desiccation, where sediments appear to have accumulated layer-by-layer over several hundred thousand years. The mineral jarosite was also detected in this region. On Earth, jarosite is deposited in or altered by salty, highly acidic water. The high sulphur-to-chlorine ratio, and the high iron content of the salty rocks encountered by Opportunity, suggest relatively warm (>265 K), acid-sulphate conditions; as does the absence of calcium carbonate —which reacts to form gypsum in acid sulphate solutions.

Recent results from the OMEGA instrument in Mars Express have revealed multiple, ancient deposits containing clay minerals that can only form in the presence of liquid water. This reinforces the hypothesis that ancient Mars may have been wetter, and possibly warmer, than it is today, and suggests interesting targets for further consideration. Other discoveries made by the Mars Express High-Resolution, Stereo Camera (HRSC) show that, even over the past few million years, the surface of Mars has been locally shaped by flowing water, lava, and ice.

Since ExoMars is a "search for life" mission, candidate sites must contain evidence suggestive of a past or present habitable environment, supported by both morphology and mineralogical composition information. A good landing ellipse would include multiple instances of rocky outcrops whose composition is considered suitable for the long-term preservation of biomarkers (e.g. clays, sulphates, etc.) in association with long-lasting fluvial, lacustrine, or hydrothermal signatures. However, it is the buried deposits that constitute the primary science target.

A site with the above characteristics would also be scientifically suitable for the NASA Rover mission.

In cooperation with its NASA counterpart, the ExoMars PS will organise a Landing Site Working Team (LSWT) to assist with the landing site selection tasks. The LSWT will regularly inform the ESWT and the PM of their progress.

The intention is to implement a process identical to that successfully used for the Mars Exploration Rovers (MER) and for the Mars Science Laboratory (MSL) missions. A first landing site workshop, open to the scientific community at large, will identify and evaluate the science interest of potential landing sites best suited to achieve the mission search-for-life objectives, within the constraints imposed by engineering requirements, planetary protection requirements, and the need to ensure a safe landing. The results of this workshop will form a basis for prioritising and narrowing down the list of sites under consideration. Other landing site workshops will follow at regular intervals, typically once a year, with the goal to complete landing site certification approximately one year before launch.

The identification of the landing sites for the 2018 mission will be a joint responsibility of NASA, ESA, the ESWT and the 2018 Project Teams. It must be a decision by consensus.

6.5.2 EDL Demonstrator Landing Site

Being the EDL Demonstrator mainly a technological mission, the emphasis for the site selection activities will be exclusively on achieving a safe landing.

The ExoMars project will undertake the certification of suitable landing sites for the EDL demonstrator. They will perform this work in cooperation with NASA and the Jet Propulsion Laboratory.

7 SCIENCE OPERATIONS AND DATA

7.1 ExoMars Operations Concept

7.1.1 2016 Mission

ESA will establish the ExoMars Mission Operations Centre (MOC) in its European Space Operations Centre (ESOC), in Darmstadt (D).

NASA will be responsible for the 2016 mission launch. ESA will undertake checkout and operations of the spacecraft. ESA will also be in charge of operations, data acquisition, data transmission, and distribution for the Orbiter and EDL Demonstrator.

NASA will manage the science operations of any NASA orbiter instruments, but commanding and telemetry monitoring of Orbiter instruments will be implemented by ESOC, through coordination with the NASA responsible groups.

Science operations for the ESA EDL Demonstrator instruments will be managed by ESA. Programming of the timeline and telemetry monitoring of EDL Demonstrator instruments will be the responsibility of ESOC through coordination with the ESA responsible groups.

7.1.2 2018 Mission

NASA will be responsible for the launch, checkout, and operations of the 2018 mission spacecraft until touchdown. Once on the surface of Mars, NASA will control their Rover through commands transmitted by ESA's ExoMars Orbiter or by other communication assets, if available.

ESA will set up a Rover Operations Control Centre (ROCC) at ALTEC, in Turin (I), to control the ExoMars Rover through commands transmitted via the ExoMars Orbiter or by other communication assets, if available.

Through the PS, ESA will manage the science operations for the Rover's Pasteur instruments. ESA will also coordinate science data analysis activities for the daily planning of Rover operations at the ROCC. The latter is fundamental for mission success. The PS, in coordination with the ESWT and the instrument teams, will establish a Rover science operations strategy similar to that used by NASA Rover missions. This will include a Science Operations Working Team (SOWT), with subgroups having specific research foci, for short and long-term Rover operations planning.

The Agency's European Space Astronomy Centre, ESAC, in Villafranca del Castillo (E), will play a key role for archiving and providing access to the ExoMars Rover scientific data.

The primary responsibility for developing the payload operations strategy for the ExoMars missions is with the ESWT.

7.2 Mission Operations Centre

ESA will conduct all ExoMars mission operations through its Mission Operations Centre (MOC). These operations include:

- Mission planning.
- Spacecraft monitoring and control.

- Orbit and attitude determination and control.
- On-board software maintenance.
- Operations support for the Orbiter scientific instruments, commensurate with spacecraft and ground segment constraints. The individual instrument operations will be the responsibility of each specific instrument team.
- Distribution of scientific data, as required, e.g. Rover data to the ROCC.

Mission operations commence at separation of the 2016 ExoMars spacecraft from the launcher and continue until the end of the mission, when ground contact with the last spacecraft element is terminated. A similar scenario applies for the 2018 mission.

The MOC will also have the overall responsibility for planning and coordinating effective data-relay services for the ExoMars Orbiter and Rover. The MOC must therefore secure effective interfaces with the appropriate NASA Operations Centre(s). If feasible, it is envisioned to make use of NASA satellites as backup, or as a means to increase the mission's science return.

7.3 Rover Operations Control Centre

The Rover Operations Control Centre (ROCC) will be responsible for all ExoMars Rover science operations on the Martian surface, which include the following functions:

- The optimisation of the ExoMars Rover science return through the definition and implementation of an efficient and cost effective science ground system.
- The definition and implementation of a rapid science data analysis capability, to be performed with the ESWT or an ESWT-designated team of investigators, to support the Rover and Pasteur payload science operations. It is expected that, at least during the nominal mission, the scientists will need to work in the ROCC. All necessary facilities, including conference rooms, projectors, screens, internet access, etc. must be made available at the ROCC.
- The definition of operations for all surface mission phases, including the planning and execution of the Rover egress manoeuvre from the landing platform.
- The planning and implementation of instrument operation timelines and command sequences as inputs to the Rover Operations Plan (ROP).
- The coordination and verification of all command sequences generated by the Rover instrument teams for the operation of the Rover and the instruments in the Pasteur payload before their submission to the MOC. In some cases this may require validating or testing using the Rover Engineering Model in a Mars Simulation Facility, which will be located within the ROCC.
- The creation, together with the ESWT and at regular intervals, of mission-highlights and main scientific results summaries.
- In coordination with ESAC, the preparation of guidelines for science data archiving, and the creation of the Pasteur Scientific Data Archive (PSDA), as part of the ESA Planetary Science Archive (PSA).
- In coordination with ESAC, making pre-processed data, including the Pasteur Scientific Data Archive available to the scientific community in accordance with ESA-approved procedures.

It is the responsibility of the ESWT and the Pasteur selected scientists, to provide timely inputs for the ROCC to support these tasks.

7.4 Data-Sharing Policy

From the very beginning, in 2003, the Pasteur scientific community realised that the multidisciplinary nature of the search for signs of life on Mars requires that the instruments in the Rover complement each other. This is necessary to identify suitable geological targets for the conservation of biomarkers, and for the recognition of life-related signatures and compounds. This convergence must be extended to the interpretation of the scientific results.

Investigators will only have a few hours to process and interpret instrument data to propose a sequence of Rover activities for the next sol. To achieve this rapid-reaction scientific response it is essential to develop a critical mass of knowledgeable scientists able to promptly analyse the mission's results. Granting all selected scientists immediate and complete access to all Pasteur results is the only way to bring this about.

ESA will also ensure that the appropriate means are in place to provide a real-time flow of the main ExoMars scientific results to the public. This also requires a fast scientific response.

Summarising, ESA will grant all Pasteur-selected scientists immediate and complete access to the whole ExoMars Rover data set and to the utilisation of the data processing software, whether developed by the Agency or otherwise. ESA will ensure that appropriate and visible credit is given to all parties contributing instruments or data analysis tools in all publications, whether in the web or in peer-reviewed science journals. A plan to this effect will be proposed by the ESWT.

The ownership, access, use and dissemination of raw and calibrated data resulting from all scientific instruments in the ExoMars missions shall be governed by Chapter III, Section II, Paragraphs 1 through 3, of the Rules on Information, Data and Intellectual Property, ESA/C/CLV/Rules 5 (Final), as adopted by the ESA Council Resolution on the Rules concerning Information, Data and Intellectual Property, ESA/C/CLV/Res. 4 (Final) [RD 8] . The duration of the agreed prior access period, as mentioned in Par. 3(b) of the referenced document, shall be 6 months after reception and distribution of the data by the MOC. For the Rover, this privilege shall be granted collectively to all Pasteur selected scientists (instrument and IDS teams).

For the Orbiter, the agreed 6-month, prior-access privilege shall be granted to each instrument team. However, ESA expects that science teams will work in a collaborative manner to maximise the mission's science return. Orbiter science results deemed necessary to prepare or to conduct ExoMars Rover operations shall be made available immediately to the Rover scientific community.

The 6-month restricted access privilege shall be granted collectively to all EDL Demonstrator instrument scientists. Engineering measurements performed during the EDL Demonstrator mission shall be archived and accessible to the scientific community without further delay.

All scientific data products (the raw data sets, the relevant calibration data, the documentation, and any necessary software tools and information to use the data) shall be made available to the international scientific community not later than 6 months after reception and distribution of the data by the MOC.

Any commercial utilisation requests involving the use of information derived from the analysis of ExoMars data will be considered on a case-by-case basis, according to the rules laid down on Chapter III, Section III of [RD 8] .

The PI and Co-PI of each instrument team must ensure the timely delivery of all data products specified in the ExoMars Archiving Interface Control Document (AICD). The funding for these activities is considered to be part of an instrument cost at completion, and is therefore under the responsibility of each instrument team.

In coordination with ESAC, the Rover Operations Control Centre (ROCC) will prepare and maintain the Pasteur Scientific Data Archive (PSDA) within six months of the receipt of data sets from the Rover instrument teams. The ESA Planetary Science Archive standard is compatible with the NASA Planetary data System (PDS). Hence, the PSDA will become freely accessible online to all scientists.

Irrespective of the proprietary period, any data that ESA will consider useful for its communications and public relations effort shall be made immediately available to the Agency.

7.5 Data Analysis Support Policy

It is critical to the Rover mission's success that an (almost) real-time data analysis capability be guaranteed after landing. ESA, through the ESWT, will therefore coordinate the mission's data analysis effort. As part of this effort, the Agency propose to utilise part of its "Education and Public Outreach" funds to establish a number of Research Fellowship positions, specifically devoted to ExoMars Rover science data analysis. These Research Fellows will form the Rapid Science Analysis Team (RSAT); they will be collocated in the ROCC and will respond to the ESWT team of investigators supporting Rover surface operations.
The RSAT will have access to all data sets and will work towards three objectives:

- Science data analysis in support of DM landing operations;
- Science data analysis in support of Rover surface operations;
- Science data analysis in support of daily public outreach activities of ESA concerning the ExoMars mission.

Once the Rover mission has been completed, the RSAT will continue their work in support of ExoMars science data analysis. These additional activities will be coordinated with the ESWT, the body representing all ExoMars science teams.

To be effective, the RSAT must work in close collaboration with the Pasteur instrument teams; and must be operative with sufficient anticipation before the mission's critical phases. This means that the duration of these appointments will need to be extended beyond the usual two years afforded by an ESA Research Fellowship. The selection of candidates would be carried out according to ESA practices. One or more representatives of the ESWT would be invited to take part in the interview process.

The RSAT will augment the data analysis capabilities of the ExoMars science teams. ESA also considers the RSAT a powerful catalyst to foster scientific excellence and international collaboration among young European scientists. Other organisations, may also contribute to this effort, by co-financing additional RSAT positions. In particular, ESA plans to investigate whether the support of the EC may be obtained for this purpose.

7.6 Public Outreach and Science Communications

The ExoMars mission will attract much public interest. Therefore advance planning of communications and public relation activities is essential. Each instrument team commits to produce, in real time, material for public relations and World Wide Web communications. Dedicated ESA media experts will coordinate this effort.

During the development phase, ESA supports a Web home page on the ExoMars missions as an information tool for the scientific community and the general public. After launch, a more elaborated home page will include the latest news on the mission, as well as preliminary scientific results and images, as soon as they become available.

ESA will have the responsibility for planning and carrying out all ExoMars communications and public relations (activities. A general activities outline will be provided in the form of a Communications and Public Outreach Plan (CPOP). This plan must be formally agreed and adhered to by the ExoMars scientists. For the definition and detailed implementation of the CPOP, ESA will make use of professional and public communications experts who will be selected at an appropriate time. These experts will work under ESA supervision and in full coordination with the PM, PS, and the ESWT.

The active cooperation of all ExoMars scientists and Lead Funding Agencies is essential for the success of the CPR activities. Hence, the PS will initiate and identify opportunities for publishing project-related reports and scientific results. CPR material suitable for release to the general public will be made available by the members of the ESWT upon their own initiative, or upon request from the PS, at any time during the development, operational, and post-operational phases of the mission.

All ExoMars scientists are required to inform the PS and the ESWT of any scientific publications they may have produced related to the mission (its scientific objectives, preparation of its instruments, field tests, calibration or modelling, scientific results, etc.). Pointers to the relevant papers will be included in the ExoMars web site.

8 LIST OF ACRONYMS AND ABBREVIATIONS

ABP — Aurora Board of Participants (2001–2005): Aurora's Programme Board, composed of delegates from all countries supporting the Aurora Programme. From 2006 onwards it is merged with PB-HSR under a new programme board: PB-HME.

AO — Announcement of Opportunity.

Aurora — Aurora is ESA's optional programme for the human and robotic exploration of our Solar System.

CDF — Concurrent Design Facility: A tool utilised by ESA to perform mission feasibility studies. It is located in ESTEC, in the Netherlands.

CPR — Communications and Public relations.

CPOP — Communications and Public Outreach Plan: the document detailing all ExoMars communications and public relations activities to be undertaken in support of the mission.

CI — Call for Ideas.

DTC — Deputy Team Coordinator.

EDL — Entry, Descent, and Landing.

ELIPS — European Life and Physical Sciences in Space Programme: the science programme coordinating research in life and physical sciences, including exobiology, in the Directorate of Human Spaceflight and Microgravity (HME).

EMF — Exobiology Multi-User Facility: A forerunner of the Pasteur instrument payload.

EPAC — Exploration Programme Advisory Committee: The advisory body responsible for technical and scientific recommendations during the initial phase of the Aurora Programme. It has been superseded by the Exploration Science and Technology Advisory Group (ESTAG).

ERA — Exobiology and Radiation Assembly: An exposure facility that flew during 1992–1993 on ESA's Eureca platform.

ESA — European Space Agency.

ESTAG — Exploration Science and Technology Advisory Group (ESTAG). The present advisory body responsible for technical and scientific recommendations to the Aurora Programme.

ESTEC — European Space Technology and Research Centre: ESA's largest establishment, located in Noordwijk (NL).

ESWT — ExoMars Science Working Team: The group of scientists that advises ESA on all aspects of the mission affecting its scientific performance.

GCMS — Gas Chromatograph / Mass Spectrometer: Two analytical instruments that, combined, are very useful to analyse complex gas mixtures. They can provide elemental, molecular, and isotopic abundances and composition.

GEP — Geophysics & Environment Package.

IR — Infrared.

IMA	Instrument Multilateral Agreement: All the elements conducive to the timely and satisfactory completion of Instrument Projects are identified in the IMA, including the form and time of the commitments that the Partners agree to make available to the Project.
E-ICD	Experiment Interface Control Document.
IDS	Interdisciplinary Scientist.
IPM	Instrument Project Manager.
E-IRD	Experiment Interface Requirements Document.
IRev	Implementation Review.
ISS	International Space Station.
LMC	Life Marker Chip.
LPSAC	Life and Physical Sciences Advisory Committee: The advisory body issuing scientific recommendations to the ELIPS Programme.
Mb	Mega-bit: a unit of data volume equal to 2^{20} bits of information.
MER	Mars Exploration Rovers: A NASA programme that landed two very successful rovers in 2004, devoted mainly to surface geochemistry and mineralogy research.
MM	Mission Manager.
MOC	Mission Operations Centre, to be located in ESOC (D).
MOLA	Mars Orbiter Laser Altimeter: An instrument for measuring relief height in NASA's Mars Global Surveyor (MGS), orbiting the red planet since 1998.
NASA	National Aeronautics and Space Administration —the space agency of the United States of America.
PB-HME	New Programme Board for the Human Spaceflight, Microgravity, and Exploration Programmes. From 2006 onwards it carries out the tasks previously undertaken by the ABP and PB-HSR.
PB-HSR	The Programme Board for Human Spaceflight and Microgravity Research (until 2005). It grouped the delegates from all countries subscribing the ELIPS Programme. From 2006 onwards it is merged with the ABP under a new programme board: PB-HME.
PCR	Payload Confirmation Review.
PM	Project Manager.
PS	Project Scientist.
Pyr	Pyrolysis is a technique to render organic compounds volatile by subjecting them to high temperatures. It is usually employed as a first stage in combination with a GCMS, resulting in a Pyr-GC-MS instrument.
RHU	Radioisotope Heating Units: Small radioactive devices utilised to warm up items in space payloads; particularly useful when electrical power is at a premium.
ROCC	Rover Operations Control Centre.
ROP	Rover Operations Plan.

RTG Radioisotope Thermal Generators: Radioactive units for generating electrical power. They are commonly used in deep space missions when solar power generation is not practical, i.e. for the Cassini-Huygens mission to Saturn. However, small RTGs can also be used to power surface landers.

SC Science Coordinator.

SOC Science Operations Centre. An ExoMars SOC would be organised by ESA in case an Orbiter element is approved.

TC Team Coordinator: The investigator representing all Team Members participating in an instrument science team. He/she is also responsible for the organisation and reporting of the instrument team's activities.

TM Team Member: Any of the investigators that are part of an instrument science team.

TT Topical Team.

TRP Technology Research Programme: A study programme managed by ESA's Directorate of Technical and Operational Support that seeks to develop new technologies necessary for upcoming space missions.

UV Ultraviolet, usually used for ultraviolet radiation or ultraviolet light.

WG Working Group: In this document, it refers to the Pasteur Working Groups of scientists that have contributed to define the model instrument payload.

WT Working Team: One of several groups of scientists advising on specific aspects of the ExoMars mission.

A1 PROGRAMME BACKGROUND

A1.1 Search-for-Life Interest

The term Exobiology, in its broadest definition, denotes the study of the origin, evolution and distribution of life in the universe. It is well established that life arose very early on the young Earth. Fossil records show that life had already attained a large degree of biological sophistication 3.4 billion years ago. Since then, it has proven extremely adaptable, colonising the most disparate ecological niches, from the very cold to the very hot, and spanning a wide range of pressure and chemical conditions. For organisms to have emerged and evolved, water must have been readily available on our planet. Life as we know it relies, above all else, upon liquid water. Without it, the metabolic activities of living cells are not possible. In the absence of water, life either ceases or slips into quiescence.

Mars today is cold, desolate and dry. Its surface is oxidised and exposed to sterilising and degrading ionising and ultraviolet (UV) radiation. Low ambient temperature and pressure preclude the existence of liquid water; except, perhaps, in localised environments, and then only episodically. Nevertheless, numerous features; such as large channels, dendritic valley networks, gullies, water-altered minerals, and sedimentary rock formations; suggest the past action of surface liquid water on Mars —and lots of it. The sizes of Martian outflow channels imply immense discharges, exceeding any floods known on Earth.

Mars' observable geological record spans approximately 4.5 billion years. From the number of superposed craters, the oldest terrain is believed to be about 4 billion years old, and the youngest possibly less than 100 million years old. Most valley networks are ancient (3.5–4.0 billion years old), but as many as 25–35% may be more recent. Today, water on Mars is only stable as ice at the poles, as permafrost in widespread underground deposits, and in trace amounts in the atmosphere. From a biological perspective, past liquid water itself motivates the question of life on Mars. If Mars' surface was warmer and wetter for the first 500 million years of its history, perhaps life arose independently there, at more or less the same time as it did on Earth.

An alternative pathway may have been the transport of terrestrial organisms embedded in meteoroids, delivered from Earth to Mars. Yet another hypothesis is that life may have developed within a warm, wet subterranean environment. In fact, given the discovery of a flourishing biosphere a kilometre below Earth's surface, a similar vast microbial community may be active on Mars, having long ago retreated into that ecological niche, following the disappearance of a more benign surface environment. The possibility that life may have evolved on Mars during an earlier period, when water existed on its surface, and that organisms may still exist underground, marks the planet as a prime candidate to search for life beyond Earth.

A1.2 Exobiology Research in ESA

Exobiology activities in ESA started in the 1980's with the preparation of experiments for the Exobiology and Radiation Assembly (ERA). ERA flew in 1992, on board the European Retrievable Carrier (EURECA) mission, and was active for almost a year. It provided results on the exposure of invertebrates, microorganisms, and organic molecules to long-term space conditions, such as UV radiation, cosmic radiation, and vacuum.

Other experiments were conducted using Biopan, a facility externally attached to the Russian Foton retrievable satellite. Biopan's upper shell is a motor-driven lid that opens when in orbit to expose its samples to space. At the end of its ten-day mission, the lid is closed. To withstand the extreme heat of re-entry, the entire Biopan structure is protected by an ablative heat shield; and upon landing, the specimens can be retrieved and examined. Five flights took place in 1992, 1994, 1997, 1999, and 2005. Microbes, seeds, and organic molecules were subjected to the harsh low-Earth orbit environment in different manners: i.e. with and without radiation protection, to vacuum, or in the presence of a simulated atmosphere. The response of the samples was determined. It was found that unprotected bacterial spores were completely or nearly totally inactivated by the UV radiation. Thin layers of clay, rock, or meteorite material were only successful in UV shielding when they were in direct contact with the spores. Thus, concerning a possible scenario for the interplanetary transfer of life, the Biopan data suggest that small rock

ejecta of a few cm in diameter may provide sufficient protection for organisms to survive the space journey. However, micron-sized grains, as invoked in some panspermia theories, would most likely prove inadequate.

Meteorites may be natural vehicles for transporting resistant life forms across space. Hence, also on Foton, suitable meteorite analogues, the Stone experiments, were subjected to the searing environment of spacecraft re-entry. The first three rock samples were fixed to the Foton capsule's heat shield and recovered for study upon landing in 1999. The goal was to investigate why among the known meteorites believed to have come from Mars none is of sedimentary origin. Can sedimentary rocks survive re-entry? Are they altered beyond recognition by their passage through the Earth's atmosphere? Stone provided valuable results on the physical and chemical modifications undergone by sedimentary rocks during atmospheric infall. The 2005 mission contained four rock specimens, this time also including microorganisms. The goal of this work was to simulate a meteorite's atmospheric impact, and to observe to which degree the embedded bacteria and spores were affected.

From 2007 onwards, EXPOSE has been mounted on an external payload site of the International Space Station (ISS). Carefully controlled parameters, such as space vacuum and well-defined wavebands of solar UV and cosmic radiation act on the samples, which can be combined with chemical and or physically protective agents. This will help to elucidate whether, and to what extent, meteoritic material may offer enough protection for life to remain viable after a long permanence in space. It will also allow the study of long-term survivability and damage/repair mechanisms operating in microorganisms under space conditions. Finally, EXPOSE will shed light on space chemistry in the Solar System in relation to the origin of life. Organic molecules of biological interest; such as amino acids, peptides, and nucleic acids; will be exposed to characterise any variations in their stability and reactivity. Additionally, powders of clay, meteorite, and terrestrial rock will be used to model the mineral fraction present in meteoroid and interstellar dust to understand their effect as filters or as potential catalysts.

Other ESA initiatives that (will) contribute to our knowledge of important prebiotic chemical processes are Rosetta and Huygens. Rosetta will be the first mission to orbit and land on a comet. It will collect essential information to understand the formation and evolution of our Solar System. Rosetta will also help to determine whether comets could have contributed to the origin of life on Earth by seeding our planet with complex organic molecules through impacts. Light, volatile substances carried by comets may have also played an important role in the formation of Earth's oceans and atmosphere.

ESA's Huygens probe, travelling to Titan aboard NASA's Cassini spacecraft, successfully completed its mission in 2005. Many scientists consider that the present composition of Titan's atmosphere —mainly nitrogen and methane—closely resembles that of early Earth, before life began on our planet. Throughout its 2.5-hour descent, Huygens made a detailed study of Titan's atmosphere, and characterised its surface in the proximity of the landing site. Ultraviolet light from the Sun breaks methane molecules apart to produce a thick layer of smog at mid altitudes. An organic rain of methane- and nitrogen containing aerosols falls steadily onto the satellite's surface, creating an Earth-like terrain of extended river networks. The results of Huygens reveal the uniqueness of Titan in the Solar System as a planetary-scale laboratory for studying pre-biotic chemistry.

Missions to other planets not always work out the way they are planned. The Russian Mars '96 mission consisted of an orbiter, two landers, and two penetrators to perform subsurface measurements. It was launched in November 1996; but due to a failure in the rocket's upper stage, fell back to Earth. Europe had contributed many instruments to Mars '96. With no possibility of a Russian reflight, in 1997, within the Space Science Programme, work started on the design and development of the first ESA spacecraft to visit another planet: Mars Express. Mars Express, comprising an orbiter and the Beagle-2 lander, was launched in 2003 using a Soyuz rocket. Presently in operation, the mission addresses a wide variety of scientific objectives, concentrating mainly on surface geology and mineralogy; subsurface structure; and atmospheric circulation, composition and long-term evolution.

Regarding exobiology, the orbiter payload is able to identify signatures of water in liquid, solid, and vapour form. In particular, the radar experiment MARSIS has obtained data to construct underground water distribution maps to depths of a few kilometres. Other Mars Express instruments continue to break scientific ground with important discoveries. Among these are the volcanic and glacial structures observed by the High-Resolution Stereo Camera (HRSC); the detection of trace amounts of methane in the Martian atmosphere by the Planetary Fourier Spectrometer (PFS), which some scientists believe to have a biogenic origin; and the identification of water-altered minerals by OMEGA. Finally, Mars Express may also prove extremely valuable to identify life-friendly geological regions that could become candidate landing sites for ExoMars.

Regrettably, the Beagle-2 lander failed. It was to undertake a detailed chemical and morphological study of its landing site; and look for water in the soil, in rocks, and in the atmosphere. It would have sampled material from

protected niches —subsurface and rock interiors— with a mole and a rock grinder/corer mounted on a small robotic arm. Beagle-2 was designed to investigate the existence of carbonate minerals and to determine the samples' isotopic fractionation. It could also search for trace atmospheric species.

A1.2.1 The ESA Exobiology Science Team Study

As a logical progression from its activities in low Earth orbit, in 1997 ESA created an Exobiology Science Team. Its objective was to conduct a state of the art survey of exobiology research, and to formulate recommendations for the future search for life in the Solar System. The full findings were published in 1999, in ESA SP-1231, the so-called "Red Book Report" [RD 4] .

The main recommendation was that Mars should constitute ESA's primary goal, and that efforts should mainly be directed to the search for extinct life. The team identified three fundamental requirements:

1. That the landing area possess high exobiological interest. This has not been the case in past missions. Locations rich in sedimentary deposits and relatively free from wind-blown dust should be targeted.
2. That samples be collected at different sites, with a rover containing a drill to reach well into the soil and surface rocks; i.e. mobility and subsurface access.
3. That an integral set of measurements be performed on each sample and on the place it is obtained from.

The team suggested the following instruments for an exobiology package: a microscope for general examination of the samples at a resolution of 3 µm, plus a close-up camera with 50 µm resolution; an infrared or Raman spectrometer for identifying minerals and organic molecules; an alpha-proton-X-ray spectrometer (APXS) for establishing the samples' atomic composition; a Mössbauer spectrometer for studying iron mineral compositions and oxidation states; a gas chromatograph - mass spectrometer (GC-MS) assembly for isotopic, organic and inorganic molecular determination, and for chirality measurements; and an oxidants sensor.

During 1999–2000, two parallel Phase A studies were undertaken to examine the feasibility to accommodate the instrument package proposed by the Exobiology Science Team in a Surveyor-class lander. At the time, NASA had very ambitious plans for the exploration of Mars, with missions to be launched every two years. ESA saw a potential for scientific cooperation through the contribution of one or more payload elements to a future US mission. The outcome of these industrial studies was a preliminary design concept for what was called the Exobiology Multi-User Facility (EMF).

A1.2.2 The 1999 Exobiology Announcement of Opportunity

In view of a possible collaboration with NASA, in 1999 ESA issued an Announcement of Opportunity (AO) requesting proposals for exobiology experiments to be performed on Mars using the EMF. No specific flight opportunity was identified at the time. The Agency would provide the infrastructure needed for the various instruments: mechanical, control, power, thermal, and communications. It would also furnish a drill unit and a sample distribution and preparation system. The investigators were to propose the scientific instruments.

Sadly, the unfortunate demise of the Mars Polar Lander and Mars Climate Orbiter put the joint-mission scenario on hold. NASA undertook a critical review of its Mars exploration programme. This resulted in a revised sequence, with fewer and less frequent missions than previously envisioned. All landers after the twin 2003 MER rovers (dedicated to the study of surface mineralogy) were postponed to 2009 and beyond. In view of these events, the conditions for participating in a US endeavour, as defined in the 1999 Exobiology AO, were no longer realistic. ESA therefore decided to take the initiative in creating its own mission to search for life on Mars.

A1.3 The Aurora and ELIPS Programmes

Exobiology activities in ESA received a boost at the Ministerial Conference in Edinburgh, in November 2001, when the European ministers approved funding for two new important programmes: Aurora and ELIPS. The goal of the Aurora Programme is to formulate and implement a European long-term plan for the robotic and human exploration

of the Solar System, particularly of those bodies holding promise for life. The European Life and Physical Sciences in Space (ELIPS) programme complements Aurora by supporting exobiology and ISS research in low Earth orbit.

To prepare for the human exploration of Mars, the Aurora Programme must first develop the necessary technologies by conducting a number of robotic missions. These missions, however, must also resolve important scientific questions connected to exobiology, planetary protection, and hazards to human missions to Mars. For the early exploration phase, ESA assessed a range of possible missions in cooperation with scientists. This resulted in the selection of the first two missions in the Aurora Programme. They were:

- ExoMars: A Rover exobiology mission for performing *in-situ* analysis to search for traces of past and present life on Mars, and to study the environment in preparation for future human missions.
- Mars Sample Return: This challenging mission can return to Earth a small capsule carrying samples from the Martian surface. It requires a Mars Orbiter, accommodating the Earth return and re-entry capsule, and a composite Descent Module/Mars Ascent Vehicle. The Mars Ascent Vehicle delivers to a low-altitude Mars orbit the canister with the Martian soil samples. The Orbiter must then capture the canister and return it to Earth. The mission should be implemented as an international collaboration effort.

The approval of the Aurora and ELIPS programmes signalled a strong commitment by the member states to continue supporting exobiology research, and ensure the further consolidation of Europe's role as an important partner in planetary exploration.

A1.4 The 2003 Pasteur Call for Ideas

During 2002, at its Concurrent Design Facility, ESA carried out a study to define the foundations for the first Aurora mission: ExoMars. This work resulted in a preliminary mission architecture concept, and helped to estimate the level of resources that would be available to perform surface science on the Red Planet. With this information in hand, in early 2003, the Agency issued its Pasteur Call for Ideas. Scientists were invited to propose instruments for the Pasteur payload and investigations to be performed with the ExoMars Rover. In their proposals, they were also requested to describe how their instrument would complement or enhance the results provided by other instruments.

> The Call for Ideas document [RD 1] explains in detail the approach to be used for the definition of the ExoMars science: The peer review outcome of the 2003 Call for Ideas will identify the Pasteur instruments and their operational scenario. Thereafter, scientists from the selected proposing teams will be invited to form Working Groups to advise ESA on the final instrument composition of Pasteur and on its utilisation on Mars.

The scientific organisation of this Call for Ideas adopted the following approach: In proposals addressing Pasteur and ExoMars, all investigators were considered equal Team Members, collectively contributing to the scientific excellence of the proposal and the mission —that is, there were no Principal- and Co-Investigators as understood by NASA. The proposals specified a Team Coordinator whose role is to represent the Team Members, to organise and report the team's activities, and to convey any information received from ESA to the other Team Members.

The Pasteur Call for Ideas was open to investigators from all countries. However, for logistical reasons, all proposals' Team Coordinator had to be based in one of the ESA member states. The proposals also had to designate a Deputy Team Coordinator, to assist the Team Coordinator and to represent the science team. The Deputy Team Coordinator had to be from a different country than the Team Coordinator.

Large research undertakings such as ExoMars require an appropriate critical mass, and benefit greatly from an international dimension. Therefore, the requirement was introduced to include institutions from, at least, three European countries in the proposals' science teams. Furthermore, investigators were also encouraged to form multidisciplinary teams (i.e. incorporating planetary physicists, geochemists, biochemists, palaeobiologists, specialists in Antarctic organisms, instrument engineers, etc.), where Team Member skills would complement each other, resulting in a more thorough treatment of a given problem.

The scientific community's response was extremely encouraging: nearly 600 investigators; from 260 universities, research institutions, and companies; expressed their interest to participate in ExoMars. In all, 50 proposals were received. The proposing teams consisted of international, multidisciplinary groups of investigators. 30 countries were represented: a demonstration that interest in exobiology research is shared across national borders, and that scientists favour international collaboration.

A1.4.1 Scientific Peer Evaluation

During September 2003, all instrument proposals were reviewed for scientific merit by a panel of independent experts drawn from the international scientific community.

Significant effort was devoted to the careful screening and selection of the peer panel members. The Pasteur peers came from 8 different countries, and were world-renowned experts in areas such as: analytical chemistry, bioanalytical instrumentation, microbiology, palaebiology, extremophile research, environmental chemistry, biogeochemistry, aqueous geochemistry, sedimentary geology, Martian soil chemistry, mineralogy, spectrochemistry, environmental hazards, trace-element analysis, etc. Additionally, some of them had actively participated in previous landed missions on Mars. Many Pasteur peers served in editorial boards of prestigious scientific journals, and all of them had published extensively. Their curricula vitae were carefully studied, as well as their publication record, to verify their suitability and to check their independence from all proposals submitted.

The outcome of this selection was as follows*: Out of 50 proposals received, 22 scored higher than the required 75 points. Of this, 11 were "Very Good," 8 were "Excellent," and 3 "Outstanding." To demonstrate the international dimension of the proposed projects, it has been calculated that, on average, the teams consist of 11 research institutions from 5 different countries.

Additionally, there were 3 other proposals that were not recommended to be included in the next payload-definition stage because they did not target instruments. Nevertheless, the panel considered that valuable aspects of these proposals required ESA's attention, and issued specific recommendations for them.

In conclusion, the result of this Call for Ideas was very positive. A number of original and innovative proposals for novel instruments and investigations was received. At least one, and in some cases two, proposals were identified for each major instrument category. This formed a solid basis for the further definition of Pasteur and the ExoMars Rover.

A1.4.2 First Pasteur Working Groups Meeting

Following the peer review, the 22 recommended teams were invited to appoint two scientists from each proposal to serve in the Pasteur Working Groups. The objective of the Pasteur Working Groups was to advise ESA on the instrument composition of Pasteur and on its utilisation on Mars.

In March 2004, forty scientists from the Pasteur-selected teams (representing approximately 400 investigators) gathered at ESA/ESTEC for a full week. They were requested to assign priorities to the measurements needed to accurately identify signs of past or present life on Mars, and to characterise surface hazards to humans. Three Working Groups were formed; on Life Detection, Geological Context, and Environment Information. With the assistance of a small ESA team, they conducted an in-depth analysis and discussion of the mission's science possibilities and of its technical constraints —as estimated at the time. As a result of very positive discussions, the Working Groups were able to compile spreadsheets containing priority lists (essential, very important, desirable) for the scientific investigations to be performed by the Rover and its Pasteur payload. These spreadsheets also contain a comprehensive list of instruments that can be used to collect the required data, and report their technical specifications, including estimates for the resources necessary to accommodate and operate them on the Rover.

Furthermore, the science team recommended a science exploration scenario for ExoMars: It called for mobility, access to the subsurface, and research at multiple scales: starting with a visual/spectroscopic assessment of the

*ESA's Life and Physical Sciences Advisory Committee (LPSAC) and the Exploration Programme Advisory Committee (EPAC) endorsed the evaluation process and the results of this Call for Ideas on March and December 2003, respectively.

geological environment around the Rover, progressing to smaller scale investigations through the study of interesting surface rocks using a suite of contact instruments, and culminating with the collection of appropriate samples to be analysed by the instruments inside the Rover's laboratory, named after the famous French chemist and bacteriologist Louis Pasteur.

A1.4.3 ESA Pasteur Technical Board

In accordance with what was announced at the Pasteur Working Groups meeting, an ESA Technical Board (13–16 April 2004) was instituted to further assess the TRL level of the various candidate instruments, and to propose a way ahead for the technical development of the Pasteur payload. This board consisted of eight project/instrument engineers and scientists from the Exploration Programme, Space Sciences, and Technical Directorates of ESA. The Technical Board studied the material compiled during the Working Groups Meeting and the presentations submitted by the scientists; it also consulted the original proposals. Additionally, for instruments that had been subject of ESA contracts, the study officers were requested to report on their development status. As a result of its review, the Technical Board assigned each candidate instrument a colour code according to the following classification:

Green: The instrument has an advanced level of readiness: an end-to-end laboratory prototype exists and has been field-tested in a relevant environment (e.g. Antarctica, Atacama desert, etc.), or with natural samples. Alternatively, the instrument derives strongly from previous space heritage (i.e. Beagle II, Rosetta, MER, etc.) or is flight proven. The instrument's technical requirements are known, and its integration and deployment needs are well defined. The instrument is considered ready to be taken up by industry for integration and for development of the flight model.

Yellow: The instrument has a relatively advanced level of readiness: an end-to-end laboratory prototype exists; however, it may not yet have fully achieved the desired final configuration/capabilities. The prototype has been the subject of extensive ground/laboratory testing, and/or the instrument has recognisable space heritage. Although the instrument's final technical requirements can be estimated with reasonable certainty, and its integration and deployment needs are well defined, the instrument is not yet considered ready for development of the flight model. Nevertheless, the instrument can be brought to the required readiness level in a short time (< 1 year) with an immediate, though modest, investment.

Orange: Although prototypes of key components may exist, the instrument does not yet possess the required technical maturity. However, the instrument is regarded as essential or very important to achieve the mission's scientific objectives. The instrument's final technical requirements can be estimated with reasonable certainty, and its integration and deployment needs are well understood. It is considered that the instrument can be brought to the required readiness level in an acceptable time (< 1.5 years), albeit with an immediate, high financial commitment. Including this instrument in the payload introduces a certain development risk; however, this may be offset by the added science benefits, and is therefore deemed acceptable provided an aggressive instrument breadboarding effort is timely implemented.

Red: The instrument does not presently possess the required technical maturity: a suitable end-to-end prototype does not yet exist, and therefore the instrument's final technical requirements cannot be estimated with reasonable accuracy. Alternatively, the instrument's integration and deployment needs are ill defined, or it is anticipated that their implementation would result in severe technical difficulties/constraints on other Rover subsystems. The inclusion of this instrument in the payload is considered an unacceptable development risk for the project.

The outcome of this review was the descoping of the "red" instruments; whenever possible, in favour of more technically advanced instruments that could provide —or partially provide— the required scientific information. The very important "orange" instruments were retained; however, it was noted that they required immediate fast-track prototype development and testing efforts.

The results of the first Pasteur Working Groups meeting, the Technical Board's instrument list and recommendations, and the proposed way ahead regarding further Pasteur developments, were presented to the Exploration Programme Advisory Committee (EPAC) on 13 May 2004. The EPAC endorsed the work performed, approved the Agency's proposed plan of action, and authorised the release of the Pasteur instrument list, first to the scientific community for comments, and then to the industrial teams in charge of the Rover-Pasteur Phase A work.

A1.5 ExoMars Phase A Studies

ESA transmitted the Pasteur instrument list to the science teams for discussions during May-June 2004. This resulted in the correction of minor inaccuracies in the instrument list. Shortly thereafter, the Agency produced a new version of the Rover-Pasteur Phase A System Requirements Document (SRD), reflecting the revised payload composition. In parallel, the science teams were requested to prepare Instrument Information Packages (IIPs) for each Pasteur candidate instrument. The intention was to facilitate the work of the industrial teams by providing them with up to date information on the instruments and their development. The new SRD and the IIPs were sent to industry on July 2004. The instrument mass of the Phase A model payload was 24 kg.

During the second half of 2004, two Rover-Pasteur Phase A studies were conducted in consultation with the scientists and ESA. Their goal was to propose well-integrated concepts for Pasteur and the Rover, capable of realising the ExoMars science objectives. These activities were concluded in February 2005. The resulting Rover models, having a mass of approximately 250 kg, are shown in Fig. 10. The next step was to propagate the Rover designs upwards, to the Descent Module and other mission elements, to arrive to well-consolidated mission proposals. Extensions to the Phase A Mission contracts addressed this harmonisation work.

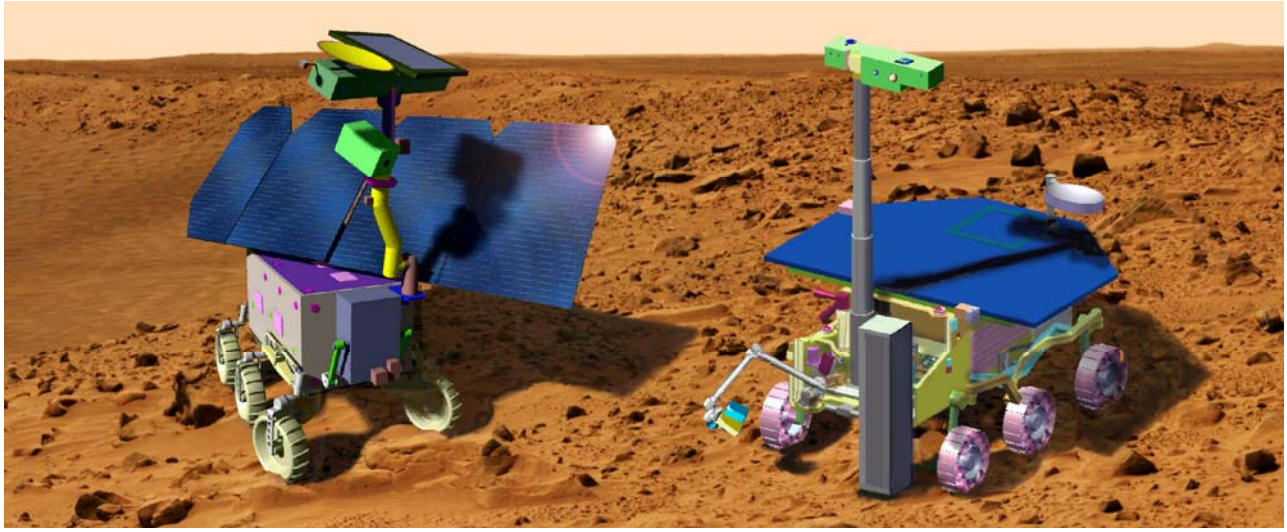

Fig. 10: Two possible Rover configurations were considered during the ExoMars Phase A. The first (left) used electric power to produce the heat necessary to survive on Mars; it therefore required a large solar array that must be pointed to the sun. Thermal conditioning in the second concept (right) were instead achieved using small Radioactive Heating Units (RHUs); this model included only a limited-size, horizontal solar panel.

A1.5.1 The Second Aurora Science Conference in Birmingham

On April 2005, European and international scientists met at the second international Aurora Science Conference, in Birmingham (UK). The goal of this gathering was to debate Mars robotic mission alternatives for 2011–2013. Three candidate missions were considered: ExoMars (Rover plus instrumented Orbiter), ExoMars (Rover only), and BeagleNet (Beagle II-derivative concept). Following scientific, technology, and programmatic presentations, an evaluation process of each mission was undertaken measured against key criteria: 1) Scientific merit of the mission in relation to the Exploration Programme objectives; 2) Mission's relative scientific excellence versus cost; 3) Timeliness of the mission's science in the international context; and 4) Importance of the mission's technology for future planetary exploration activities.

The scientists favoured the Ariane 5 ExoMars version with rover and orbital science, but recognised that this option may not be affordable in the then European budgetary conditions. For this reason, they recommended that the ExoMars Soyuz version, carrying the Rover and Pasteur, but no Orbiter, be implemented for a 2011 launch. The scientists also stressed the importance of ExoMars to prepare Europe's participation in a future Mars Sample Return mission.

Following the cancellation of the NetLander mission, the participants also requested ESA to include in ExoMars a provision for performing geophysics and meteorology investigations. This interest resulted in a proposal for the Geophysics & Environment Package (GEP).

A1.5.2 Second Pasteur Working Groups Meeting

During spring 2005, intense discussions at Programme Board level seeking to contain the overall mission cost in preparation for the 2005 ESA Ministerial Conference, resulted in a revised ExoMars mission concept: a Soyuz version, carrying the Rover and a small station, but no Orbiter. The mass allocation for the Rover and Pasteur was substantially reduced from that considered in the Phase A studies; and a new element was introduced —the GEP— which could constitute a better platform for some of the Pasteur environment measurements.

To address these payload issues, forty scientists from the Pasteur-selected teams gathered once again at ESA/ESTEC for the second Pasteur Working Groups meeting during September 2005. Also present were investigators from the GEP community and from ESA's advisory bodies, delegations, and NASA representatives. The participants recommended a payload of 12.5 kg for the Rover. They stressed that ExoMars, with its subsurface drill, will provide a unique opportunity to effectively search for life on Mars. Having reduced the Rover's instrument mass from 24 to 12.5 kg, they underlined that the recommended payload was considered the minimum necessary to do the job properly. The meeting concluded with a strong request by the scientists that the proposed 12.5-kg Pasteur payload for life detection be implemented in its entirety on board the Rover. Equally firmly was stressed the need to include the Pasteur environment instruments in the mission, and to confirm the implementation of the GEP station in ExoMars.

A1.5.3 2005 Ministerial Conference

The GEP was proposed as a small, 20-kg, autonomous package powered by Radioisotope Thermal Generators (RTG) to be provided by France. However, by mid 2005 it became known that the RTG-based GEP configuration was not feasible. The project was then asked to study a solar powered version of GEP.

The ExoMars mission was approved at the ESA Ministerial Conference in Berlin, in December 2005.

A1.5.4 Payload Confirmation Review

The 2005 Declaration on the European Space Exploration Programme – Aurora stated that the participating countries agreed to conduct an Implementation Review (IRev) of the ExoMars mission on the basis of:

- The results of the Systems Requirements Review (SRR);
- A committing industrial proposal for the development, launch, and operation of ExoMars; and
- The agreement of the participating states concerning the provision of the mission-selected instruments.

Upon concluding the Implementation Review, the participating states would confirm:

- The mission configuration (Baseline on Soyuz, Orbiter option on Ariane 5, or Baseline on Soyuz plus autonomous European data-relay communications orbiter, most likely on a second Soyuz).
- The final payload configuration; and
- The ExoMars launch date.

The decisions stemming from this review would determine the breadth of scientific objectives that ExoMars could pursue, as the choice of launcher and landing system had large implications for the Rover instrument mass and volume possibilities. The Ariane 5 configuration included a data relay Orbiter with a scientific payload..

The two main sources of information for IRev decisions would be the results of the Systems Requirements Review (SRR), and the recommendations of the Payload Confirmation Review (PCR).

The SRR was an Agency level ESA review, which was implemented according to established rules and procedures of the Agency. The SRR addressed all aspects of the mission to ensure that a coherent set of requirements existed that could allow Industry to prepare a committing technical, financial and programmatic proposal for the Baseline and optional mission configurations. This would provide two of the IRev inputs required by participating states.

Another very important component of the Implementation Review regarded the scientific excellence of the ExoMars mission. This was addressed in the Payload Confirmation Review (PCR).

A1.5.5 Third Pasteur/GEP Working Groups Meeting

Forty scientists representing the Pasteur-selected teams and the GEP community gathered at ESTEC for the 3rd Pasteur/GEP Working Groups meeting on 20 October 2006.

ESA explained the need to timely define the ExoMars mission configuration and its final payload composition to meet the 2013 launch date. It presented the proposed PCR process and criteria, which were thoroughly discussed. The assembly recommended ESA and the member states to pursue the Ariane 5 mission, the one that could credibly and timely achieve the ExoMars scientific objectives.

A1.6 Phase B1 Activities

By end 2006, as the Phase B1 progressed, it became evident that a distributed GEP, powered by solar energy, entailed a mass in excess of 70 kg and could not be implemented. Efforts to remove the GEP from the mission were met with great resistance from Germany and France, who requested that ESA involve DLR and CNES in their studies and proceed with GEP. ESA had to consider in parallel three possible mission architectures.

A1.6.1 Payload Confirmation Review (PCR)

The 2007 Payload Confirmation Review (PCR) was organised to evaluate GEP candidate instruments and to reassess the Pasteur Rover instruments, subject to the constraints imposed by each mission architecture under consideration by the Project. Candidate instruments were rated for scientific merit. A technical assessment of the readiness level of the instruments was also performed.

The PCR was organised in two subsequent steps: first, a peer review, following the same rigorous, independent procedure utilised for the 2003 Pasteur Call; and secondly, an ESA/Industry technical review. A new candidate instrument for the Rover, MicrOmega, was also presented and reviewed. The outcomes of this exercise were 16.5-kg and 12.5-kg candidate payloads for the Rover and a small, 3.5-kg payload for the GEP (please see [RD 2]). However, delegations were not satisfied with the 12.5-kg Rover payload, or with the fact that the GEP could not be included in a Soyuz-based mission. The executive indicated that a larger Rover payload and the GEP could be possible if an Ariane 5 launcher was used instead. The Programme Board (PB-HME) instructed ESA to pursue this avenue, and to seek the additional funding at the 2008 C-MIN.

A1.6.2 Fourth Pasteur/GEP Working Groups Meeting

Sixty investigators from the Pasteur and GEP communities met at ESTEC on 7–9 June 2007 for the 4th Pasteur/GEP Working Groups meeting.

ESA introduced the mission strategy that had been agreed with the Programme Board (PB-HME) to be presented at the 2008 Ministerial Conference. The new baseline would consist a 2013 launch, using an Ariane 5 or a Proton launcher, and would include a Carrier and large Descent Module (DM), but no Orbiter. Following a direct (T2), 9-month trajectory, the Carrier would go into a 4-sol orbit. The release of the DM would be "from orbit." The mission would deploy a 205-kg Rover and a 30-kg GEP on the surface of Mars. The new mission would be called Enhanced ExoMars; its cost would be expected to exceed the amount allocated at the 2005 C-MIN.

At this meeting was also first proposed to name the GEP Humboldt, after the German explorer.

Following the PCR, it was also agreed to form the ExoMars Science Working Team (ESWT). The next science gathering would therefore be called the 1st ESWT meeting.

A1.6.3 First ExoMars Science Working Team Meeting

On 7–9 April 2008, 50 scientists (representing approximately 500 investigators) from the Pasteur, Humboldt, and Descent Science teams gathered at ESTEC for the first ExoMars Science Working Team (ESWT) meeting. Also present were observers from a number of instrument Lead Funding Agencies (LFA), including NASA.

During the first day, ESA and Industry described the state of advancement of the ExoMars project, stressing their commitment to a launch in 2013. Detailed presentations covered the ExoMars mission configuration, the progress achieved in the definition of the rover and lander designs, and instrument visits planned to prepare for the Preliminary Design Review (PDR). The project team also answered questions posed by the scientific community.

On the second day were addressed the role of the ESWT and tasks requiring its support over the coming months. Also discussed were the rover and lander reference surface missions. These are the science exploration scenarios that used to drive the mission's technical design in terms of available resources (data volume for transmission to ground, required energy, etc.). The science teams were presented with the latest spreadsheets and asked to provide feedback to ensure that the scenarios were consistent with mission and instruments' requirements and capabilities. During the afternoon, the Pasteur teams gave 15-min presentations on their instruments' objectives and implementation status. The work continued well into the night, with detailed updates to the Scientific Payload Requirements (SPR) document.

The morning of the third day was devoted to presentations by the Descent Science and Humboldt teams. Also discussed were the proposed landing site selection process for ExoMars and aspects of the rover and lander reference surface missions.

A1.7 Phase B2 Activities

The mission made good technical progress during 2008, though despite the mass of the GEP implementation still proved prohibitive.

A1.7.1 2008 Ministerial Conference

The ESA Ministerial Conference was held in The Hague during November 2008. The level of funding indicated by member states for ExoMars fell short of what was needed. The financial problem, coupled with a mass crisis due to GEP and to the increase of mass in the Rover candidate instruments, caused a launch delay to 2016 and meant that a reassessment of the mission architecture, scientific priorities, and instrument complement was necessary. This resulted in the 2009 Payload Confirmation Review #2 (PCR2).

While supportive of the ExoMars mission and its objectives, ministers instructed ESA to pursue international collaboration outside Europe as a means to reduce the implementation costs of ExoMars.

A1.7.2 Payload Confirmation Review #2 (PCR2)

The 2009 PCR2 panel identified five possible payload configurations addressing the Rover mission's scientific objectives, spanning the mass range 16.7 to 12.3 kg (called Options A–E respectively), with correspondingly decreasing science capabilities (please see [RD 3]). The panel also underlined the need to preserve the 2.0-m depth reach in the drill, for scientific and reliability reasons. Finally, the panel recommended removing the GEP from ExoMars and flying its Humboldt instruments on an upcoming mission.

On the basis of the Rover mass that the 2016 mission configuration being considered at the time could accommodate, the ExoMars Project proposed to implement Option D. Option D included seven instruments (PanCam, WISDOM, Ma_MISS, MicrOmega IR, Raman, MOMA, and MARS-XRD). The Programme Board (PB-HME) accepted this as a "minimum payload" and recommended to the project exploring possibilities to reinforce the exobiology content of the Rover mission.

A1.7.3 Second ExoMars Science Working Team Meeting

On 1–2 July 2009, 50 scientists from the Pasteur and Humboldt science teams gathered at ESTEC for the second ExoMars Science Working Team (ESWT#2) meeting. Also present were instrument managers from a number of Lead Funding Agencies (LFA), including NASA, and ExoMars engineers from Industry.

ESA described the outcome of bilateral discussions in Plymouth with NASA aiming at implementing a cooperative programme for the robotic exploration of Mars. The scenario reported would result in an orbiter mission dedicated to data relay and the study of atmospheric trace gases in 2016, and postpone the launch of the ExoMars rover until 2018. This news dominated the discussions for the rest of the meeting, and was considered by the participants a worrying development.

ESA also presented the state of advancement of the ExoMars Rover design and discussed a new Rover Reference Surface Mission —with the reformed Pasteur payload— for the case of one communications pass per sol.

Finally, the Pasteur teams gave 15-min talks on their instruments' status and science preparation, highlighting useful areas where the participation of investigators from other teams (selected and non-selected for ExoMars) may be of help. The teams presented examples where interested colleagues had already contacted them.

A1.8 Present ExoMars Status

On November 2009, ESA and NASA signed a Letter of Agreement to proceed forward with a Mars Exploration Joint Initiative (MEJI). This is a collaborative framework programme initially including two missions, in 2016 and 2018.

Under MEJI, ExoMars has become a programme whose objectives will be pursued in 2016, with an Orbiter and an EDL Demonstrator; and in 2018, with the ExoMars Rover.

ESA, NASA, and JPL are working to ensure a successful technical and scientific implementation of these missions.

A2 ROVER PASTEUR PAYLOAD

A2.1 Selected Instruments

Panoramic camera System (PanCam):

PanCam is designed to perform digital terrain mapping for the ExoMars rover mission. A powerful suite, consisting of a wide-angle, stereoscopic, colour camera pair, complemented by a high-resolution, colour camera, PanCam will allow characterising the geological environment at the sites the rover will visit —from panoramic (tens of metres) to millimetre scale. It will also be used to study outcrops in detail, and to image samples collected by the drill before they are delivered to the analytical laboratory for analysis. PanCam can also be used for atmospheric studies.

Principal Investigator (PI): Andrew Coates, MSSL/University College London, London (UK)
Co-PI – High-Resolution Camera: Ralf Jaumann, DLR/IPF, Berlin, (D)
Co-PI – Wide-Angle Cameras: Jean-Luc Josset, Institute for Space Exploration, Neuchâtel (CH)

Shallow ground-penetrating radar (WISDOM):

The WISDOM radar will be very useful to characterise subsurface stratigraphy to a depth of 3–5 m and a resolution in the order of 2 cm. WISDOM will allow constructing subsurface maps. Most importantly, WISDOM will identify layering and help select interesting buried formations from which to collect samples for analysis. Targets of particular interest for the ExoMars mission objectives are well-compacted, sedimentary deposits that could have been associated with past water-rich environments. This ability is likely fundamental to achieve the Rover's scientific objectives, as subsurface drilling is a resource-demanding operation that can require several sols.

Principal Investigator (PI): Valérie Ciarletti, LATMOS (F)
Co-PI: Svein-Eric Hamran, FFI, Oslo (N)
Co-PI: Dirk Plettemeier, TU-Dresden (D)

Borehole infrared spectrometer (Ma_MISS):

Ma_MISS is a miniaturised IR spectrometer integrated in the drill tool. It will image the borehole wall created as the drill is operated. Ma_MISS provides the unique capability to study subsurface stratigraphy and geochemistry *in-situ*. This can be very important since samples may be altered following their extraction from their cold, subsurface conditions (–75 °C). The analysis of unexposed material by Ma_MISS, together with data obtained with the spectrometers located inside the rover, will be crucial for the unambiguous interpretation of the original conditions of Martian rock formation.

Principal Investigator (PI): Angioletta Coradini, INAF, Rome (I)
Co-PI: Maria Cristina De Sanctis, INAF, Rome (I)

MicrOmega IR:

Following the crushing of the collected sample, MicrOmega IR will be the first instrument to be used in the analytical laboratory. MicrOmega will study mineral grain assemblages in detail to try to unravel their geological origin, structure, and composition. These data will be vital for interpreting past and present geological processes and environments on Mars. Because MicrOmega IR is an imaging instrument, it can also be used to identify grains that are particularly interesting, and assign them as targets for Raman and MOMA-LDMS observations. This is a very useful property.

Principal Investigator (PI): Jean-Pierre Bibring, Institut d'Astrophysique Spatiale, Orsay (F)
Co-PI: Nicolas Thomas, University of Bern (CH)
Co-PI: Frances Westall, Centre de Biologie Moléculaire, CNRS, Orléans (F)

Raman Spectrometer:

The Raman spectrometer provides geological and mineralogical context information for igneous, metamorphic, and sedimentary processes, especially water-related geo-processes (e.g. chemical weathering, chemical precipitation from brines, etc.). In addition, it also permits detecting a wide variety of organic functional groups. Thus, Raman can contribute to the tactical aspects of exploration by providing a quick assessment of organic content prior to the analysis with other instruments, like MOMA. Raman constitutes a high-priority instrument for establishing the geological context of samples, for assessing habitability, and for helping with the detection of bulk organics and certain key pigments.

Principal Investigator (PI): Fernando Rull, Universidad de Valladolid/CAB (E)
Co-PI: Sylvestre Maurice, Observatoire Midi-Pyrénées, Toulouse (F)

MARS-XRD:

MARS-XRD is an X-ray diffractometer for the analysis of crushed rock samples. The study of the different minerals will be used to constrain the geological evolution of the sites the rover will visit. The instrument's targets include all the silicate minerals, such as clays, and sulphates. Furthermore, the identification of concentrations of carbonates, sulphides, or other aqueous minerals could be indicative of a past Martian hydrothermal system capable of preserving traces of life. This instrument also possesses an X-ray fluorescence capability that can provide useful atomic composition information.

Principal Investigator (PI): Lucia Marinangeli, IRSPS, Pescara (I)
Co-PI: Ian Hutchinson, University of Leicester (UK)

Mars Organic Molecule Analyser (MOMA):

MOMA is the largest instrument in the rover, and the one directly targeting biomarkers. MOMA is able to identify a broad range of organic molecules with high analytical specificity, even if present at very low concentrations, in samples obtained with the ExoMars drill.

MOMA will answer questions about the possible origin, evolution and distribution of complex organics and life on Mars. These important studies will be carried out through two main activities: 1) the detection of organic molecules, and 2) the possibility to establish their biotic or abiotic source by identifying the distribution of molecules and their chirality. Besides studying the samples collected by the drill, MOMA will also analyse gases in the Martian atmosphere.

MOMA has two basic operational modes: Laser Desorption Mass Spectrometry (MOMA-LDMS), to study large macromolecules and inorganic minerals; and Gas-Chromatograph Mass-Spectrometry (MOMA-GCMS), for the analysis of volatile organic molecules. In MOMA-LDMS, crushed drill sample material is deposited in a refillable container. A high-power, pulsed laser ionises the sample, and the resulting ions are guided into the mass spectrometer and analysed. In the case of MOMA-GCMS, sample powder is used to fill one of twenty single-use ovens. The oven is sealed and heated up stepwise to a high temperature in the presence of a derivatisation agent. The resulting gases are separated by gas chromatography and delivered to the shared mass spectrometer for analysis. This process is useful for small, volatile organic molecules, such as amino acids.

The MOMA instrument implements a highly innovative combination for the robotic analysis of organic molecules, including the derivatisation of primary amines to elucidate their chirality.

Principal Investigator (PI): Fred Goesmann, Max-Planck-Institut für Sonnensystemforschung, Lindau (D)
Co-PI – MS: Luann Becker, John Hopkins University, Baltimore (USA)
Co-PI – GC: François Raulin, LISA, Universités Paris 12 & 7 (F)

Close-Up Imager (CLUPI):

The 2009 PCR2 review panel considered CLUPI "essential for achieving the mission's scientific objectives." CLUPI provides much needed, high-resolution imaging capabilities (20-micron resolution) to study the depositional environment, and potential morphological signatures of past biological activity preserved on the texture of surface rocks. This is a function that exceeds the possibilities of PanCam.

Following the removal of the robotic arm for mass and cost saving reasons, the project must review its accommodation.

Principal Investigator (PI): Jean-Luc Josset, Institute for Space Exploration, Neuchâtel (CH)
Co-PI: Frances Westall, Centre de Biologie Moléculaire, CNRS, Orléans (F)
Co-PI: Beda Hofmann, Natural History Museum Bern (CH)

Life Marker Chip (LMC):

LMC performs a liquid extraction of molecules from the crushed sample material obtained by the drill. LMC allows simultaneously detecting multiple molecular biomarkers and non-biogenic organic molecules employing specific antibodies in a microarray inhibition/competition immunoassay. The antigenic targets have to be predefined, and antibodies have to be made against them, assuming that the specific antibodies will find corresponding antigens in the collected Martian samples. Each LMC chip will contain a library of antibodies for resolving simultaneously up to 25 target molecules.

The present plan is to use this instrument to provide an independent verification of the outcome of MOMA. As such, LMC will be able to process a reduced number of samples (4 or 5).

Please note: The 2009 PCR2 review panel concluded that "the LMC concept provides a promising approach for astrobiology research, its aims are innovative, and the results could be fascinating." However, it also found that the instrument had not then reached a sufficient technology readiness level, particularly concerning the state of development of functional antibodies and their stability under mission conditions. The PCR2 panel recommended that LMC be developed further and considered for a later Mars mission. Until now, the project has not studied its accommodation in the rover.

Principal Investigator (PI): Mark Sims, University of Leicester (UK)
Co-PI: David Cullen, Cranfield University (UK)

A3 ORBITER MODEL PAYLOAD

#	Acronym	Description	View Modes	Observation Modes	
1	SFTIR	Solar Fourier Transform IR Spectrometer: **Broad survey** of trace gases with high precision	Solar Occultation only; passive radiative cooler	2 Solar Occultations per orbit (~24/day); processing interferorgrams throughout orbit	
1	SLNIR	Solar-Nadir IR Mapper: Detection and mapping of **specific** trace gases	Solar occultation; nadir and limb viewing; heat sink required (assumed to be provided by s/c)	2 solar occultations + dayside nadir/limb (60 min) on each orbit	
2	Sub-mm	**Sub-mm Spectrometer profiler/mapper Atmospheric temperature & winds plus H2O and specific trace gases**	**Nadir and limb, including away from velocity vector**	**Continuous operations switching between nadir, space, different limb; observe both sides of ground track**	
2	TIR	**Thermal IR profiler/mapper spectrometer or radiometer for atmospheric temperature and dust, plus H2O and some trace gases**	**Nadir and limb views, including away from velocity vector**	**Continuous operations switching between nadir, space, different limb; observe both sides of ground track**	
2	WAC	**Wide Angle Camera imaging atmospheric phenomena for discriminating between surface, dust clouds, & ice clouds**	**push-frame operation with .GE. 2 color bands; requires alignment with ground track motion**	**Cross-track (nearly orthogonal to velocity vector) horizon-to-horizon**	
3	HRCSC	High Resolution Color Stereo Camera: **Surface imaging**	~1 m/pixel ground sampling (at nadir) with TDI; fore/nadir/aft views	Designated targets of opportunity; requires alignment with ground track motion (mitigation needed)	

		MASS (kg)	Accommodation Issues	Power (W, avg.)	Power (W,Peak)	Data Vol. (Mbits/day)	Comments
	SFTIR	40	Anti-sun radiator a critical component	50	50	1900	On-board processing of interferograms;
	SLNIR	20	Includes 5 kg for radiator not previously included	20	30	900	Formerly labelled TGM/SOIR; Radiator too large to place on instrument; assumed on s/c
	Sub-mm	**27**	**Power estimates reflect heritage technologies**	**80**	**99**	**800**	**Instrument includes ability to slew to view direction; some indications that power need could be cut in half**
	TIR	**10**	**Data volume assumes mapping of selected trace gases**	**20**	**20**	**1000**	**Assumed 100 interferograms per orbit; T/dust/ice sounders typically return less data**
	WAC	**3**	**Onboard processing (e.g., image compression) done in instrument (not on spacecraft computer); gimbal to stay cross-track?**	**5**	**5**	**500**	**Typically framing cameras, some with spectral filters so direction important**
	HRCSC	25	5 kg added to account for low design maturity; 5 kg added for camera positioning platform; assumed 10 min/orbit peak power and 10 W standby	15	50	3000	1.6 Gb/image (compressed) Requires velocity vector alignment during imaging; if s/c slews, other instrument radiators must be protected
	Totals	**125**		**190**	**254**	**8100**	**At max range/aphelion power**
	Allocations	**110**	**Aug-09**	**140**		**3000**	**150 kbps for single station pass**