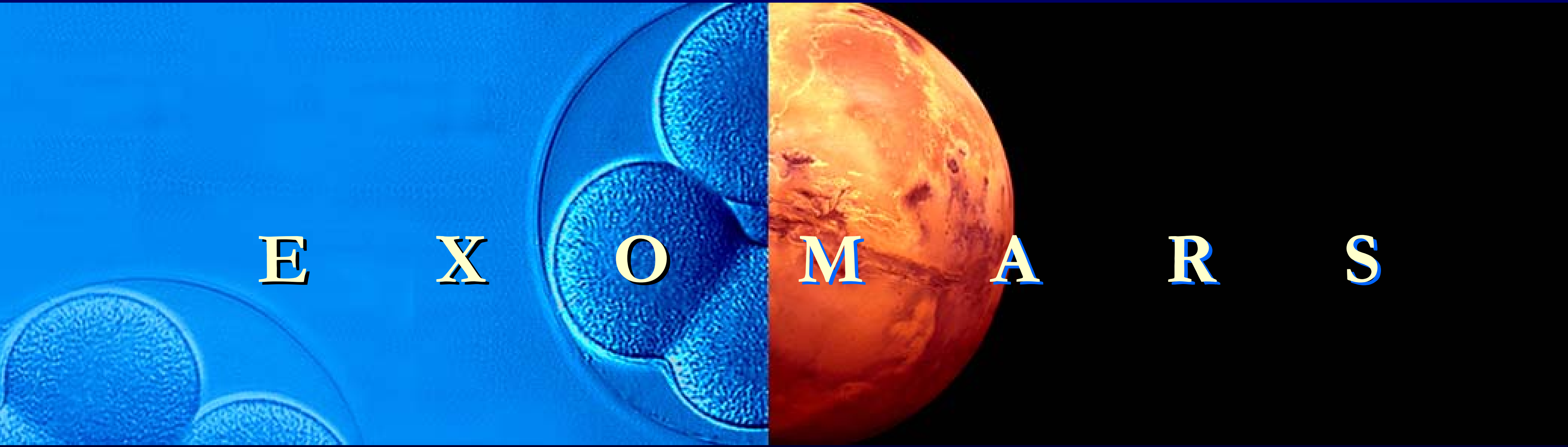


Mission Objectives & Science Strategy

J. L. Vago and the ExoMars project team

Solar System Working Group – SSWG
8 September 2005, ESA HQ (F)

The Aurora Programme

ESA's new programme to prepare for the human exploration of the Solar system.

Characteristics:

- Defines a long-term space exploration strategy for Europe;
- Focuses on exploration infrastructure and technology development;
- Robotic missions in preparation of future human ones;
- Synergy between scientific and technological objectives;
- Provides a framework for cooperation with other space agencies.

What is ExoMars?

- Is the first mission of ESA's Aurora Exploration Programme.
- ExoMars will deploy two science elements on the Martian surface: a Rover carrying the Pasteur payload, and a fixed station —the Geophysics/Environment Package (GEP).

Scientific Objectives:

Pasteur Rover:

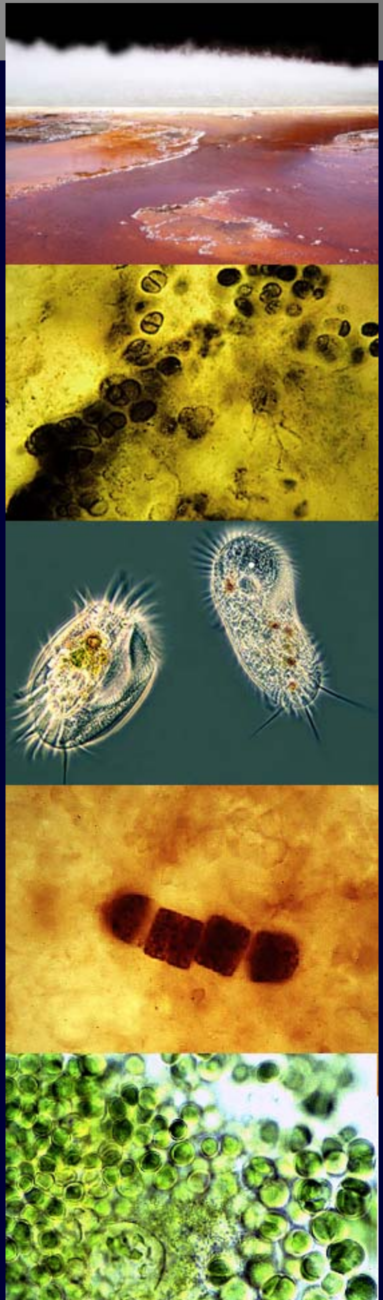
- To search for traces of past and present life on Mars;
- To characterise, in the shallow subsurface, vertical distribution profiles for water and geochemical composition.

GEP:

- To measure planetary geophysics parameters important to understand Mars's evolution and habitability;
- To study the surface environment and identify hazards to human missions.

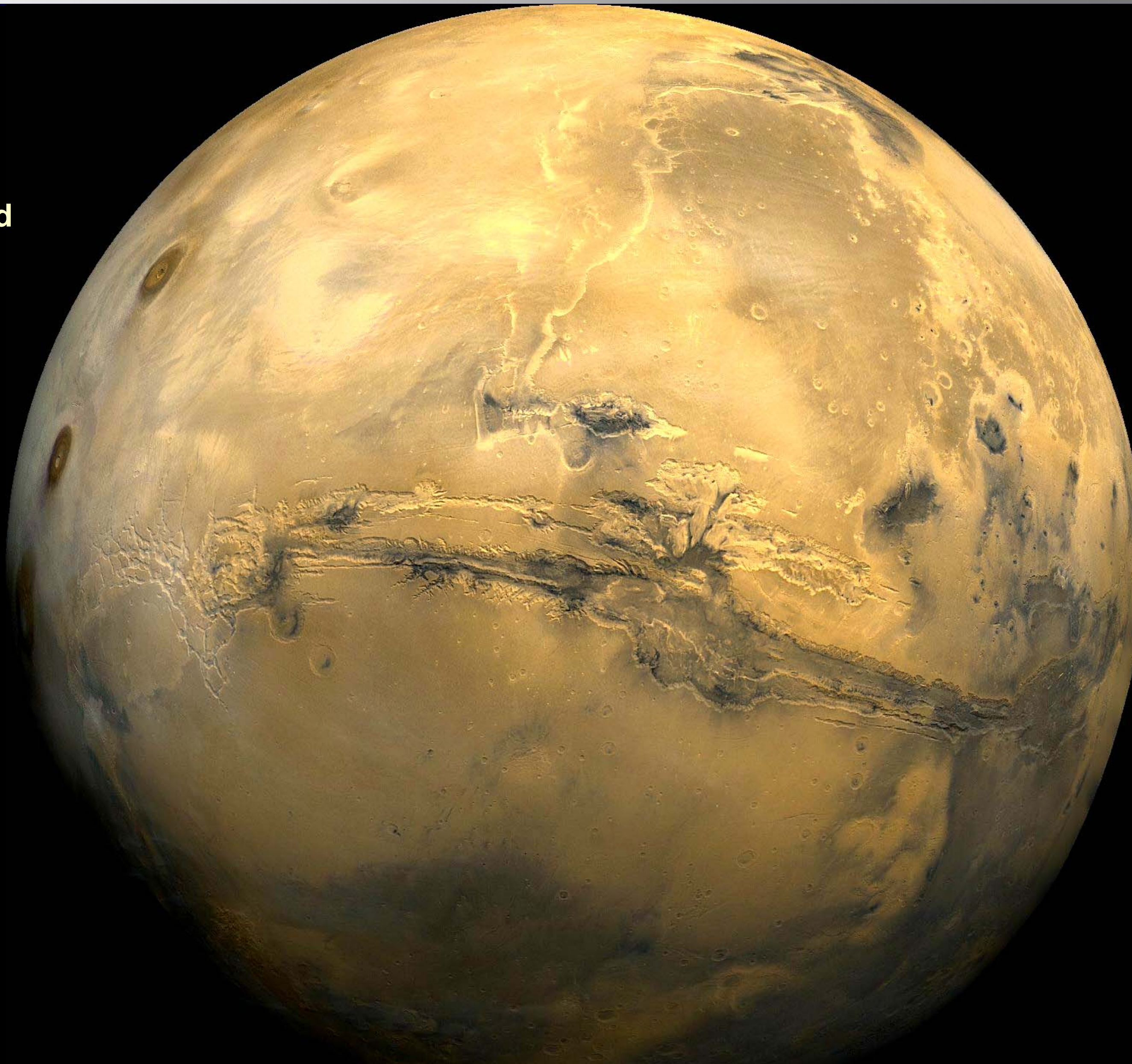
Technology Objectives:

- To develop a European capability to land large payloads on Mars;
- To demonstrate high surface mobility and access to the subsurface;
- To prepare technologies necessary for a Mars Sample Return mission.



Why life on Mars?

- Early in the history of Mars, liquid water was present on its surface;
- Some of the processes considered important for the origin of life on Earth may have also been present on early Mars;
- Asteroid and comet impacts may have been less severe on Mars, favouring the survival of life;
- Establishing if there ever was life on Mars is <u>fundamental</u> for planning future human missions.

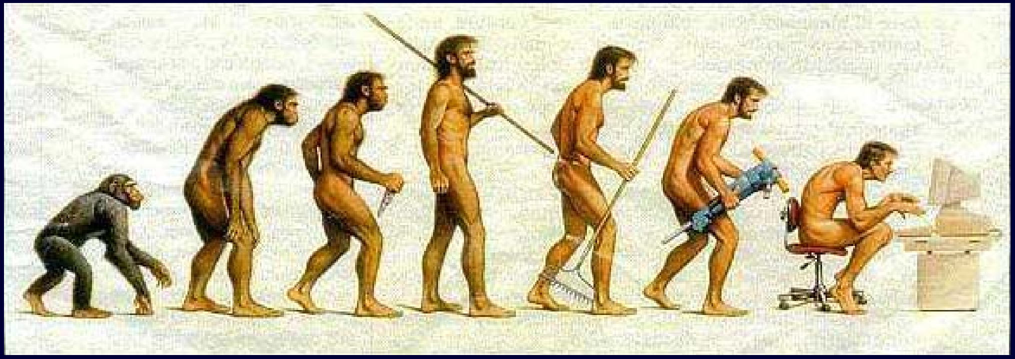


What is life?

A self-sustained chemical system capable of Darwinian evolution.

That is, a system that can transfer its molecular information via self-replication, and evolve through mutations.

Drawback: Evolution occurs over thousands of generations;



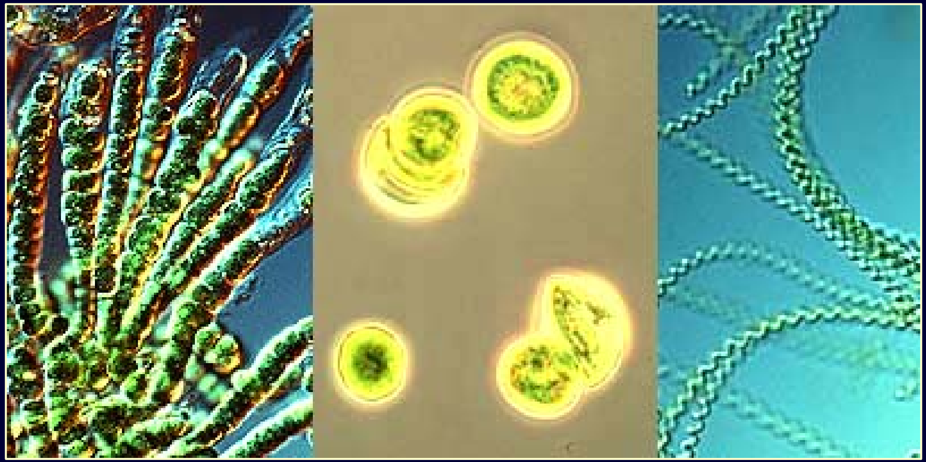
Exchange of molecular information is difficult to verify.

We need a definition that is useful for our space mission.

What is life?

Life is cells: Every living thing is cellular

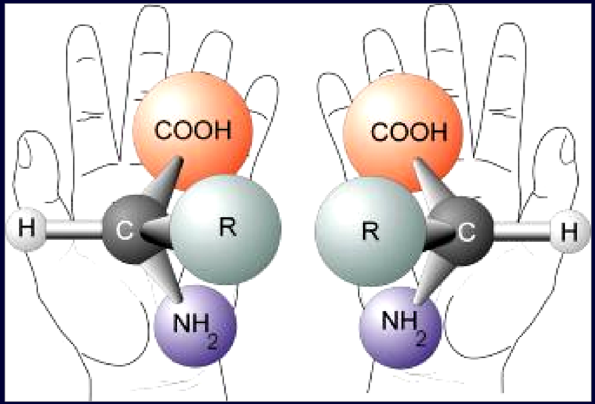
- Cells need liquid water:
  - Stabilises biopolymer configuration;
  - Chemical reactant in key biological processes;
  - Transport medium.
- Cells require proteins and nucleic acids (for replication and catalysis)
- Cells require sugars (as energy source and backbone for nucleic acids)
- Cell membranes are built with phospholipids



Life has homochirality

Biomolecules exist in 2 mirror forms (enantiomers).
Life uses only one enantiomer, and not the other:

- Left-handed (L) aminoacids
- Right-handed (R) sugars

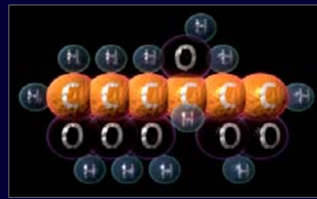


What to search for?

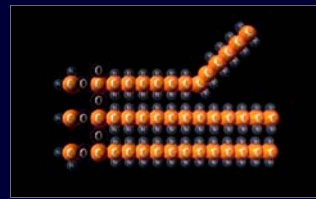
- **<u>Extant Life</u>:** Biological markers, such as:

Amino acids

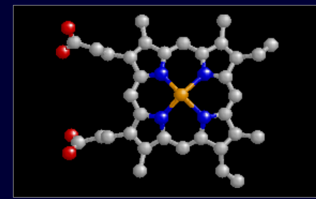
Nucleotides



Sugars



Phospholipids

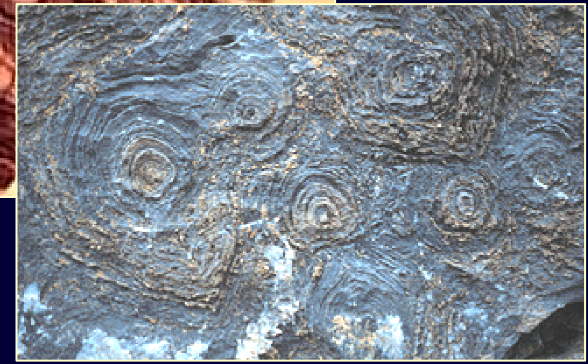


Pigments

…

- **<u>Extinct Life</u>:**
  - Organic residues of biological origin;
    (chemical, chiral, spectroscopic, and isotopic information)
  - Images of groups of fossil organisms and their structure;
    (morphological evidence)
  - Geochemical and mineralogical effects of biology on the environment.
    (second order)

Ancient life on Earth Stromatolite formations



Where to search?

- Liquid water is presently unstable on the Martian surface (P & T are too low).
- The solar UV dose is harmful to unprotected life and organic compounds.

➔ the search for extant life will focus on the subsurface.

Preferably on warm spots with evidence of water deposits at accessible depths, as identified from remote sensing satellites, i.e. Mars Express & MRO.

- For extinct life, the search strategy relies on looking for well-preserved biosignatures, i.e. encased in the geological record as microfossils.

➔ the search for extinct life will also focus on the subsurface.

On sites occupied by bodies of water over extended time periods:

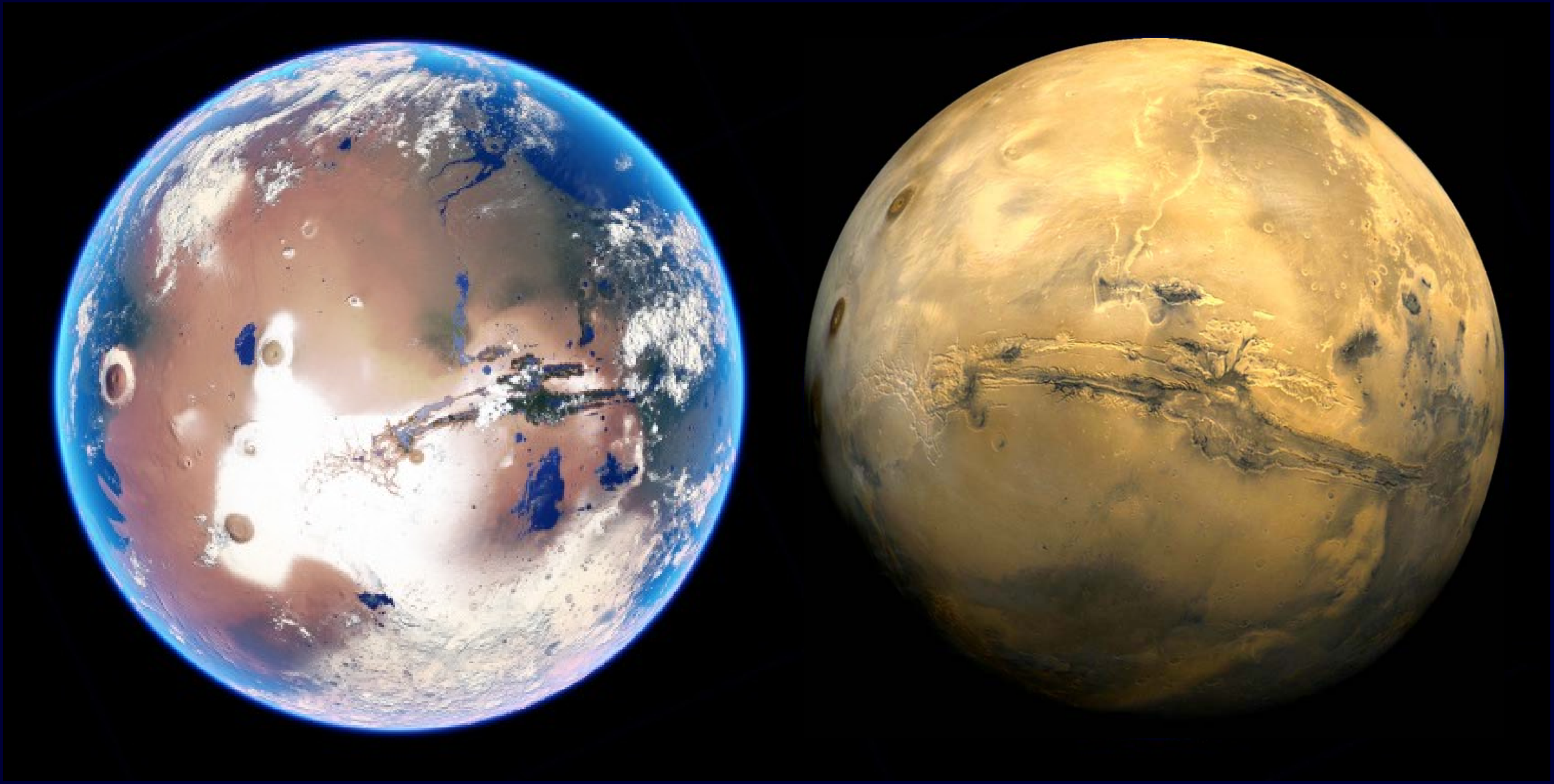
- Sedimentary deposits in ancient lake beds,
- Remains of hydrothermal systems;
- Outflow regions of past water channel systems.

Present Mars surface conditions

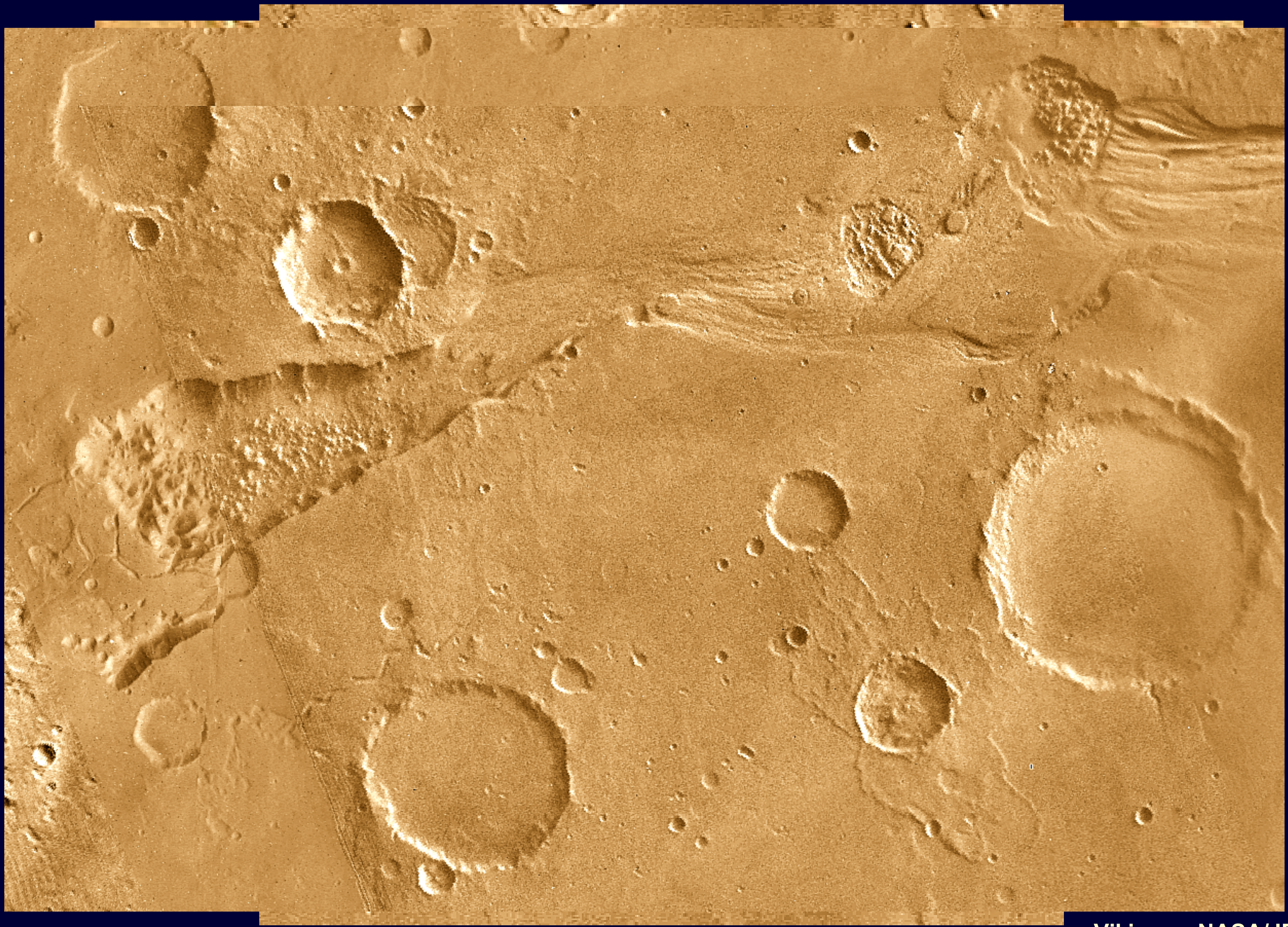
Characteristics:

- An extremely dry, cold environment;
- A very tenuous atmosphere;
- Dust everywhere;
- Very high UV radiation;
- Comparatively high ionising radiation.

Was Mars warm and wet in the past?

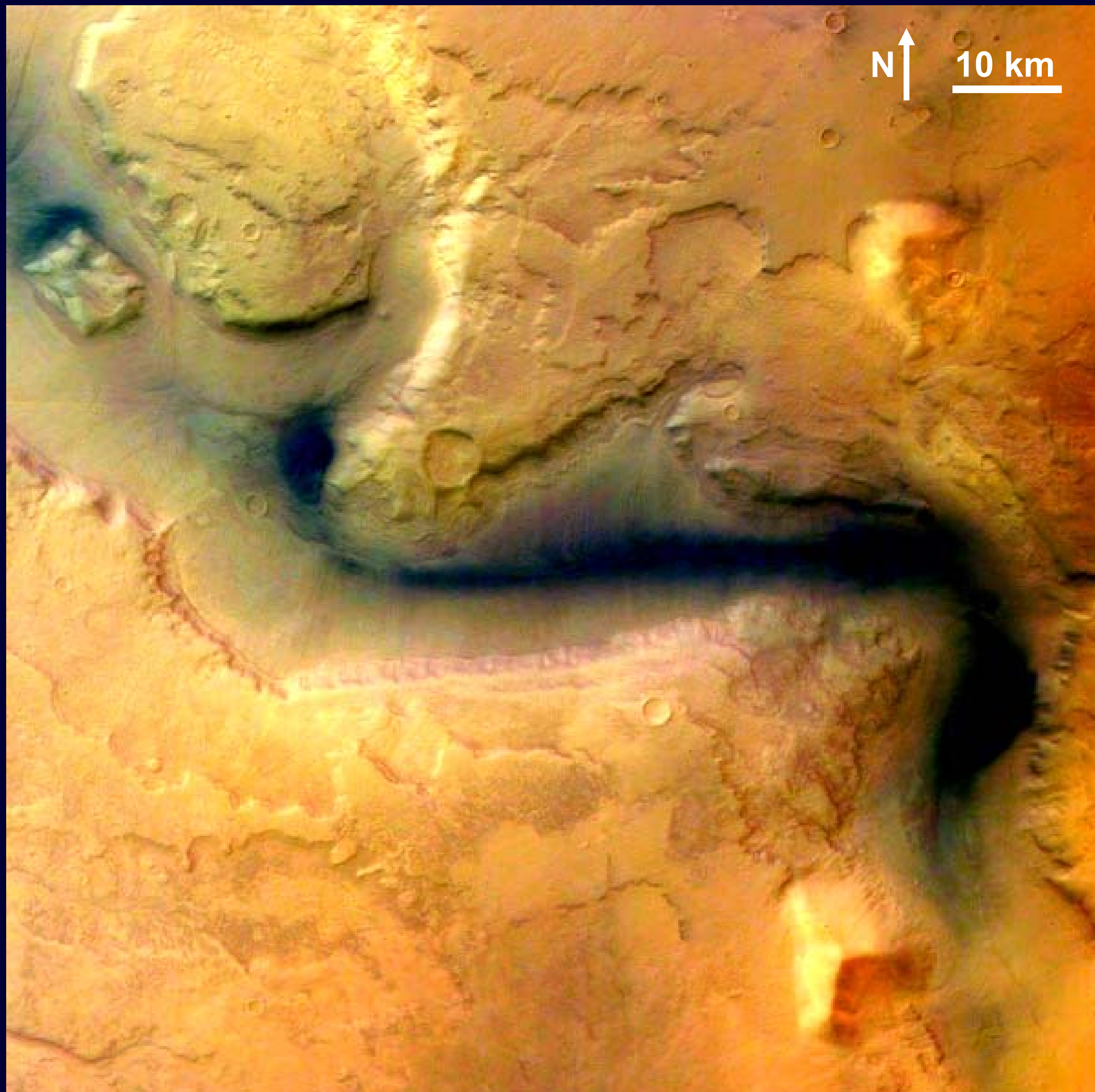


Evidence of past flowing water



Viking — NASA/JPL

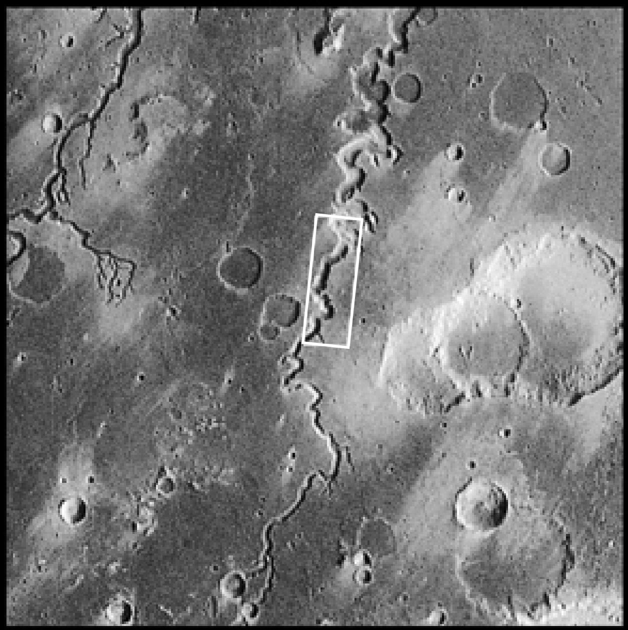
Evidence of past flowing water



Channel in Reull Vallis, east of the Hellas basin (41°S, 101°E)

MEX — ESA/DLR/FU Berlin

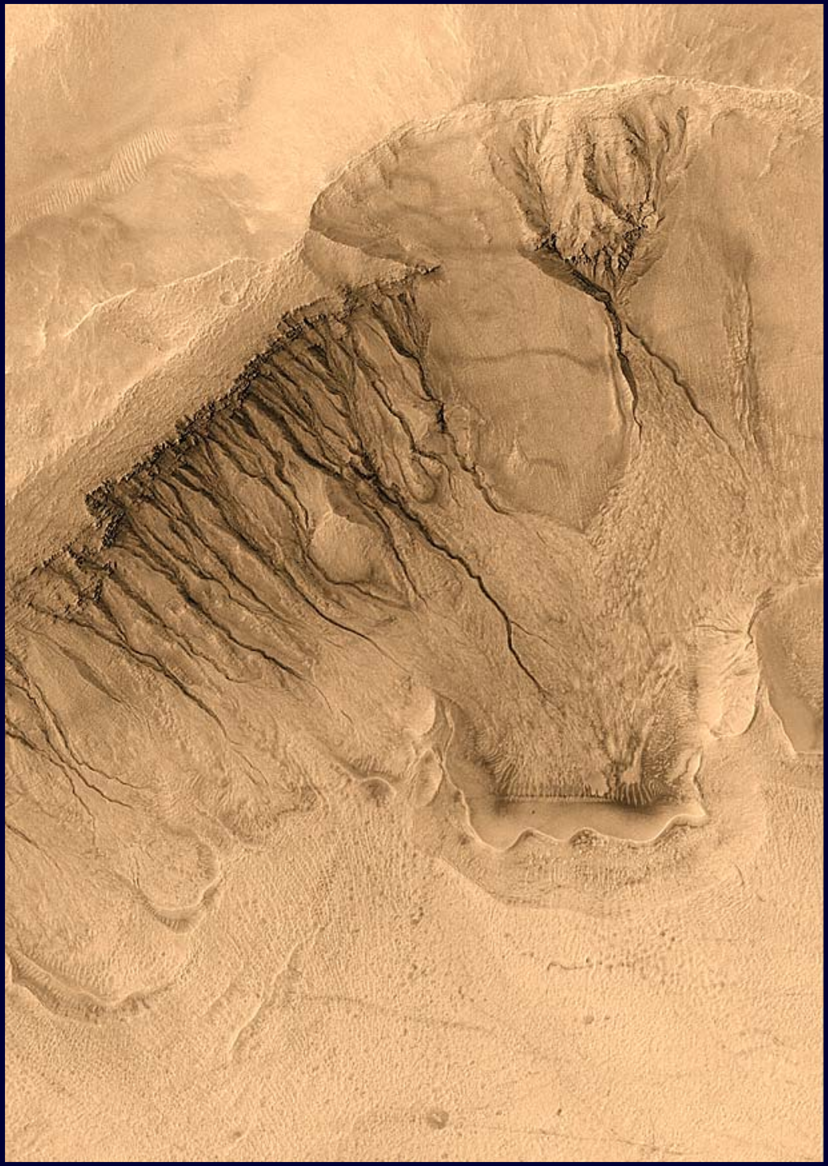
Evidence of continuous water flow



Nanedi Vallis basin (5°N, 315°E)

MGS — NASA/JPL/MSSS

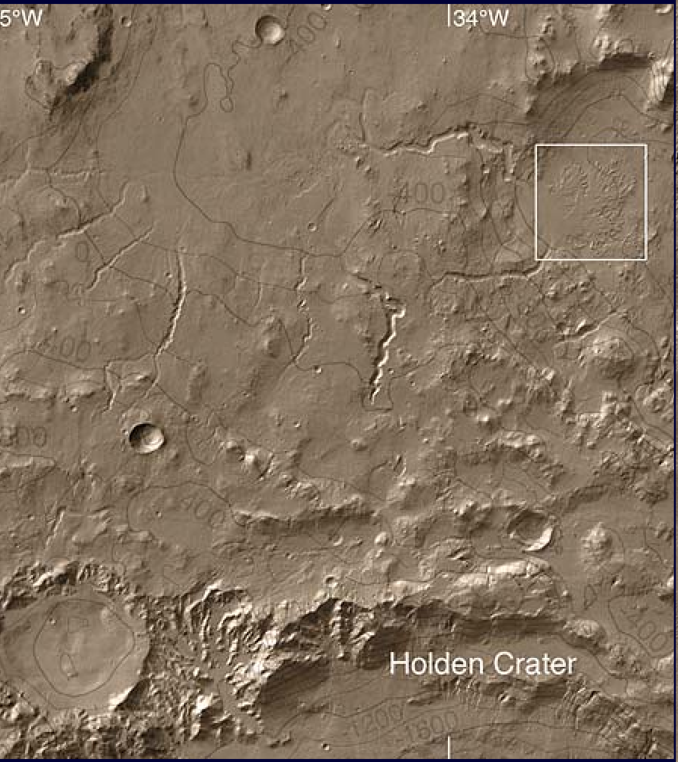
Evidence of recent flowing water

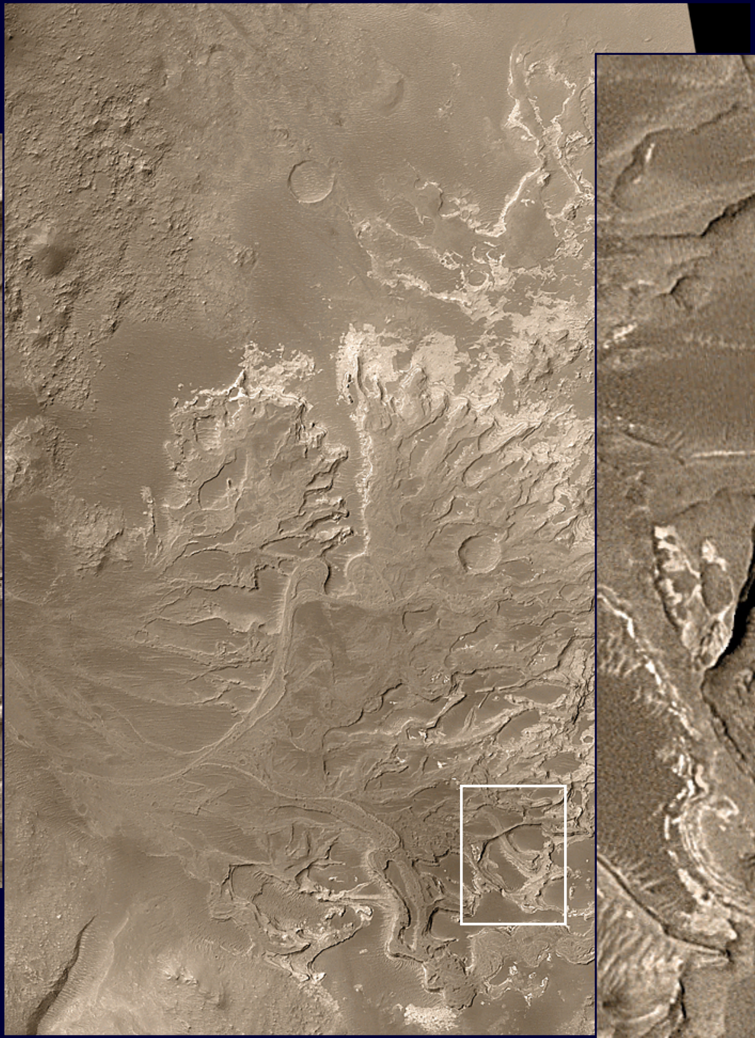


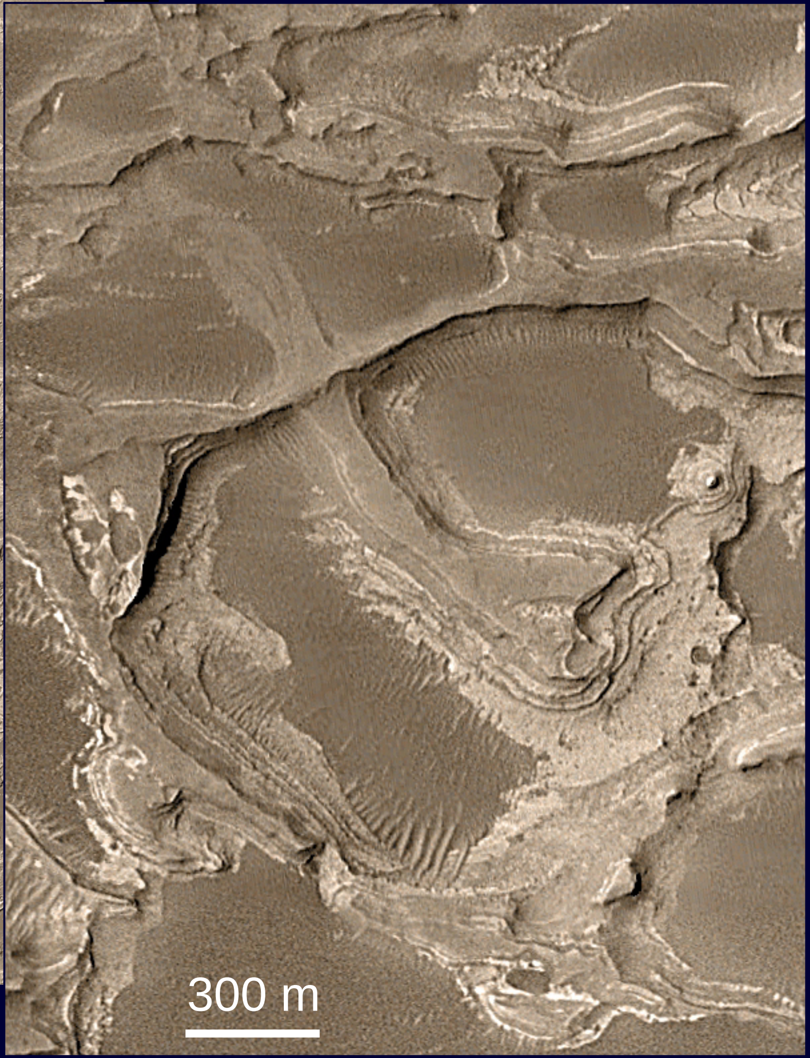
Gullies in impact crater on Newton basin (39.0°S, 166.1°W)

MGS — NASA/JPL/MSSS

Evidence of sedimentary deposits



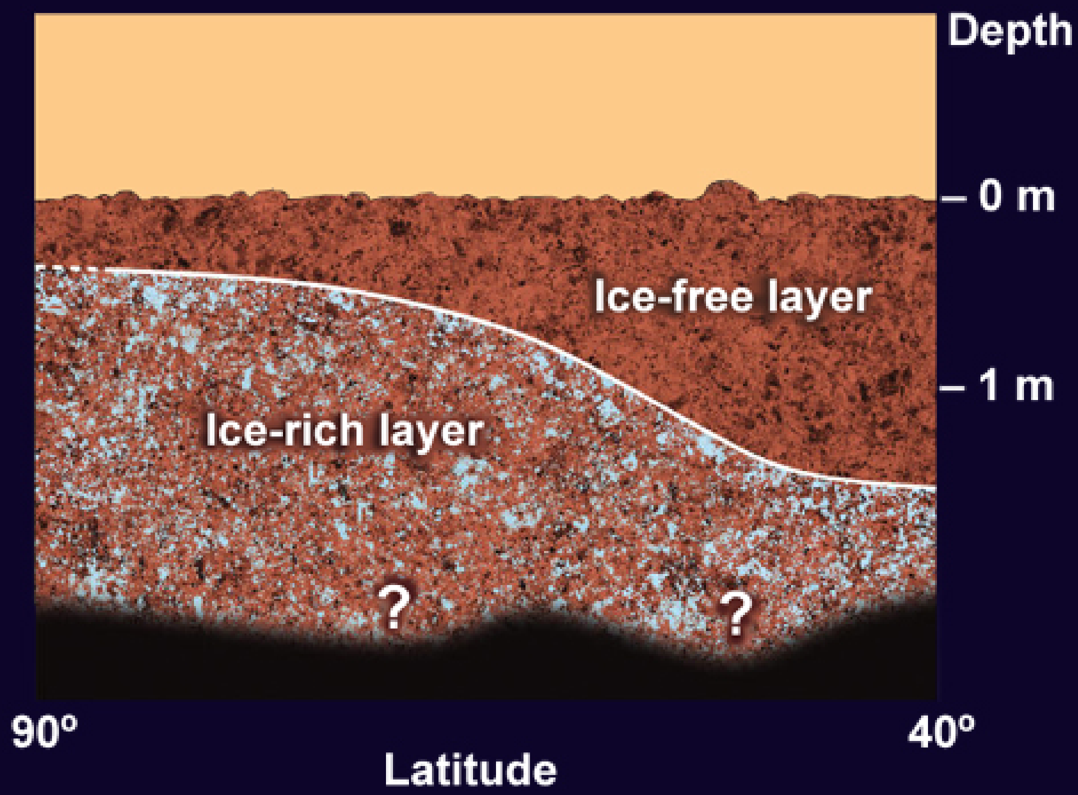


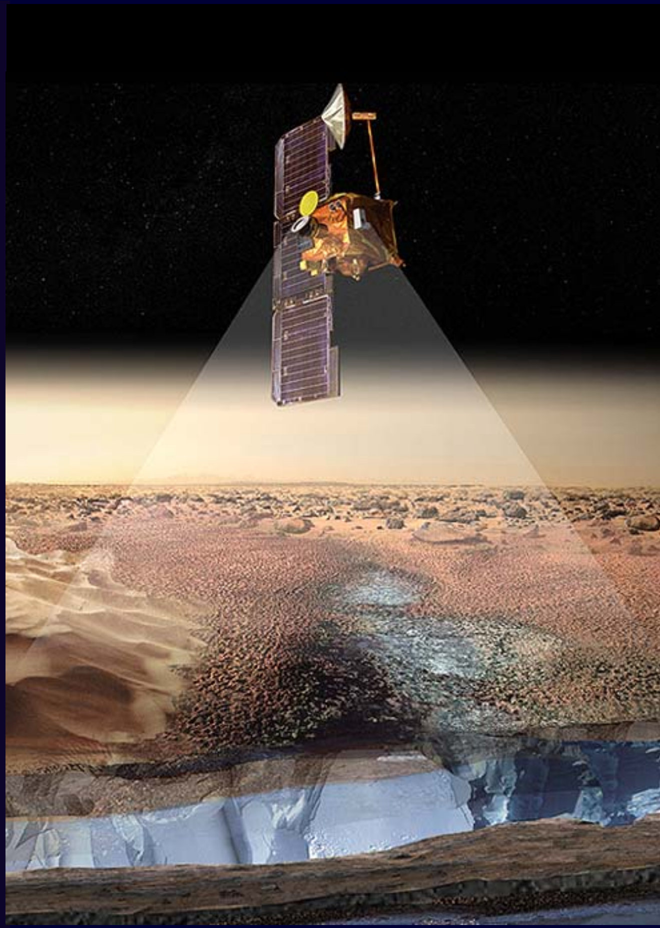


Sedimentary distributary fan NE of the Holden crater (24.3°S, 33.5°W)

MGS — NASA/JPL/MSSS

Evidence of underground ice deposits





MER results


Opportunity Discovers Evidence of Past Water on Mars
Microscopic Imager view of Vugs & Spherules
Pancam Image of El Capitan

Vikings 1 & 2 (1976)

The Viking GC/MS did not detect organics above part per billion (ppb) level.

However, the detection limit for amino acids was in the tens of ppm range.

At ppm level, amino acids from $\sim10^7$ cells per gram of Martian soil would not have been detected!

Viking did not rule out the possibility of life on Mars, past or present.

Mission science strategy

- ExoMars integrates its Pasteur instrument payload into a high-mobility rover:
  Range: 10+ km on the Martian surface;

- Rover searches for traces of past and present life on Mars:
  Bio-organic molecules, underground and within surface rocks
  (chemical, chiral, spectral, morphological & isotopic investigations);

- Rover characterises geological/geochemical environment:
  Optical and spectral analyses at multiple scales, and reactive chemical species;

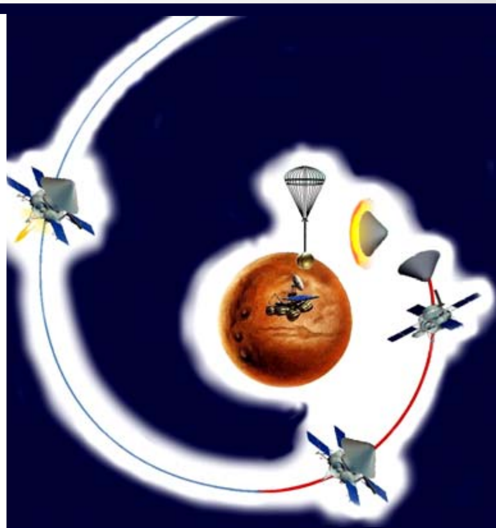
- ExoMars lander contains a Geophysics/Environment Package (GEP) to investigate:
  Seismology, thermal gradient, dust, atmospheric parameters, and radiation (ionising & UV);

- Data relay function for surface elements to be provided by NASA satellites (MRO);

- Compatible with solar energy, ExoMars preserves maximum flexibility in landing sites to accommodate latest scientific results (MEX & MRO): Latitudes between –15º and +45º;

- ExoMars is a Category IVc mission; hence it can target interesting regions with subsurface life potential.

Present mission scenario



Launch:	May-June 2011 on Soyuz 2b, from Kourou.
Arrival:	June 2013, after the dust storm season.
Spacecraft:	Carrier + Descent Module.
Landing:	Direct entry, from hyperbolic arrival trajectory.
Landing Range:	Latitudes between –15º and +45º, all longitudes; Altitude ≤ 0 m relative to the MOLA zero level.

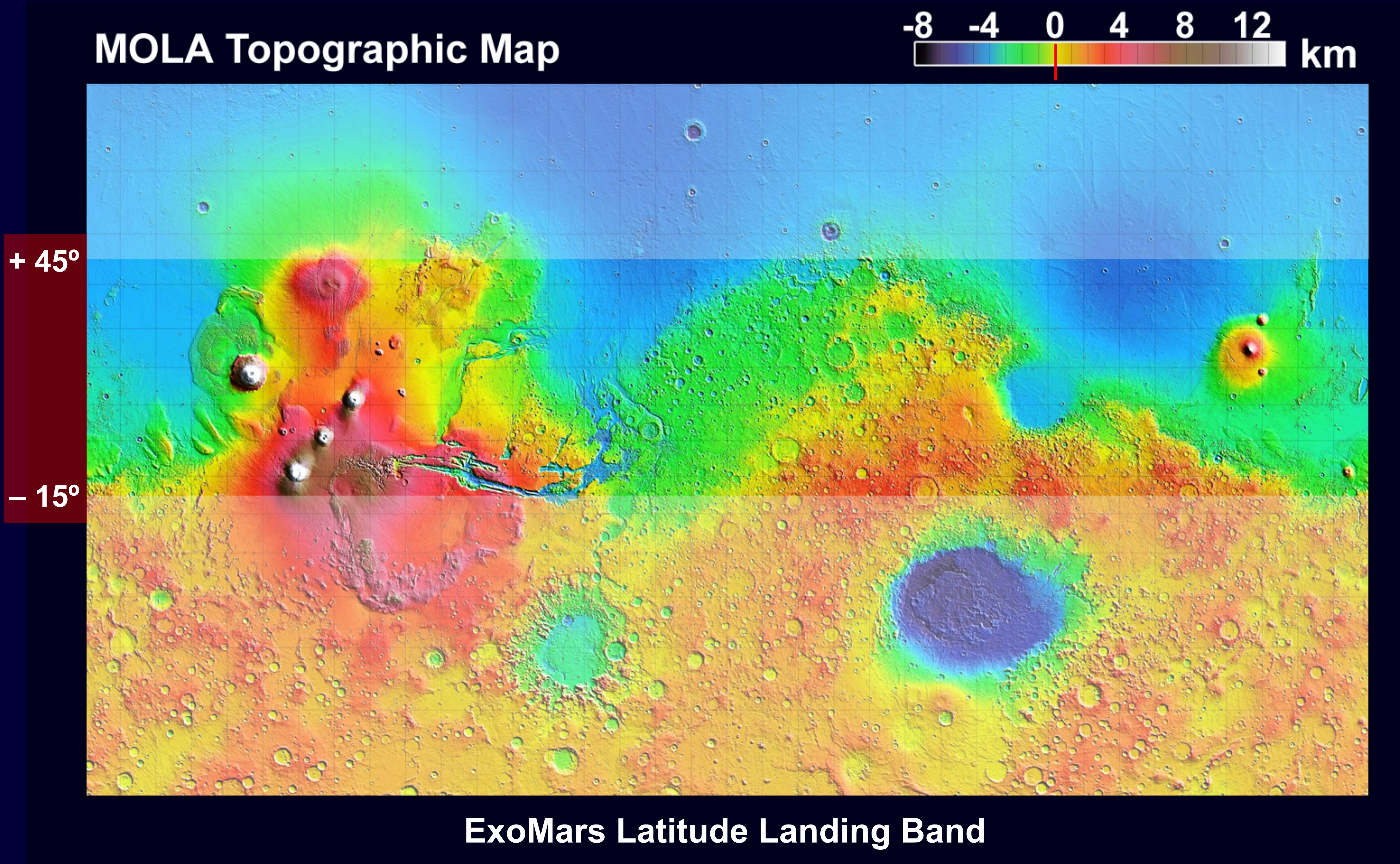
Landing System: Based on parachutes, retrorockets, and airbags.

Science:

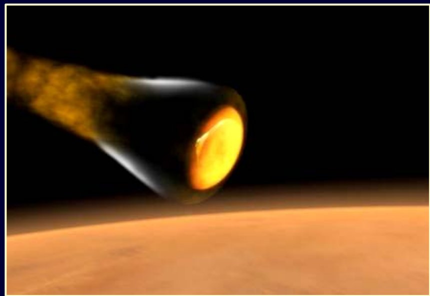
- Rover and Pasteur payload: (mobility 10+ km) — Rover mass: 120 kg, includes: Drill System and SPDS; Instruments (8 kg); Surface lifetime 180 sols.
- Geophysics/Environment Package: (fixed station) — Mass ≤ 20 kg, includes: Instruments (5 kg); Surface lifetime ≥ 6 years.

Data Relay: To be provided by NASA satellites.

Landing sites

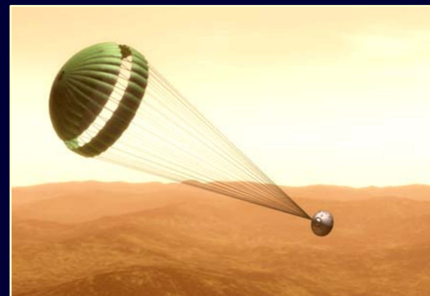


Landing challenge



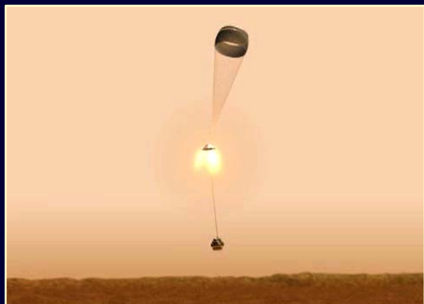
Entry

Energy dissipation via aerodynamic drag;
Velocity Range: start ~5.4 km/s end ~430 m/s.



Parachute Descent

Energy dissipation via aerodynamic drag;
Velocity Range: start ~430 m/s end ~85 m/s.



Powered Descent

Energy Dissipation via rocket thrust;
Velocity Range: start ~85 m/s end ~2–20 m/s.

Landing

Energy Dissipation via viscous damping or plastically crushed material;
Velocity Range: start ~2–20 m/s end 0 m/s.

Airbag designs

Vented airbags

Military heritage;
Absorbs impact by deflating in a controlled manner;
More mass efficient;
Can be used for larger masses;
Does not require self-righting mechanism;
More sensitive to tangential speed.

Non-vented airbags

Pathfinder & MER heritage;
Multiple bounces on the surface;
Less mass efficient, but it works;
MER is considered system’s upper mass limit;
Requires self-righting mechanism.

Pathfinder Airbags (NASA/JPL)

Rover science strategy

- To land on, or be able to reach, a location possessing high exobiology interest for past and/or present life signatures, i.e. access to the appropriate geological environment.
- To collect scientific samples from different sites, using a rover containing a drill capable of reaching well into the soil and surface rocks. This requires mobility and access to the subsurface.
- At each site, to conduct an integral set of measurements at multiple scales: beginning with a panoramic assessment of the geological environment, progressing to smaller-scale investigations on interesting surface rocks —using a suite of contact instruments,— and culminating with the collection of well-selected samples to be studied by the rover's analytical laboratory.

For life studies, it is absolutely essential that the search instrumentation provide several, mutually reinforcing lines of evidence.

No weak links: performance limitations in an instrument supposed to confirm the results obtained by another could generate confusion and discredit the whole measurement.

GEP science strategy

- **Long term**: To study Mars's internal structure, evolution, and environment by performing network science.

  To construct the network, one element at a time, using every available Mars mission opportunity.

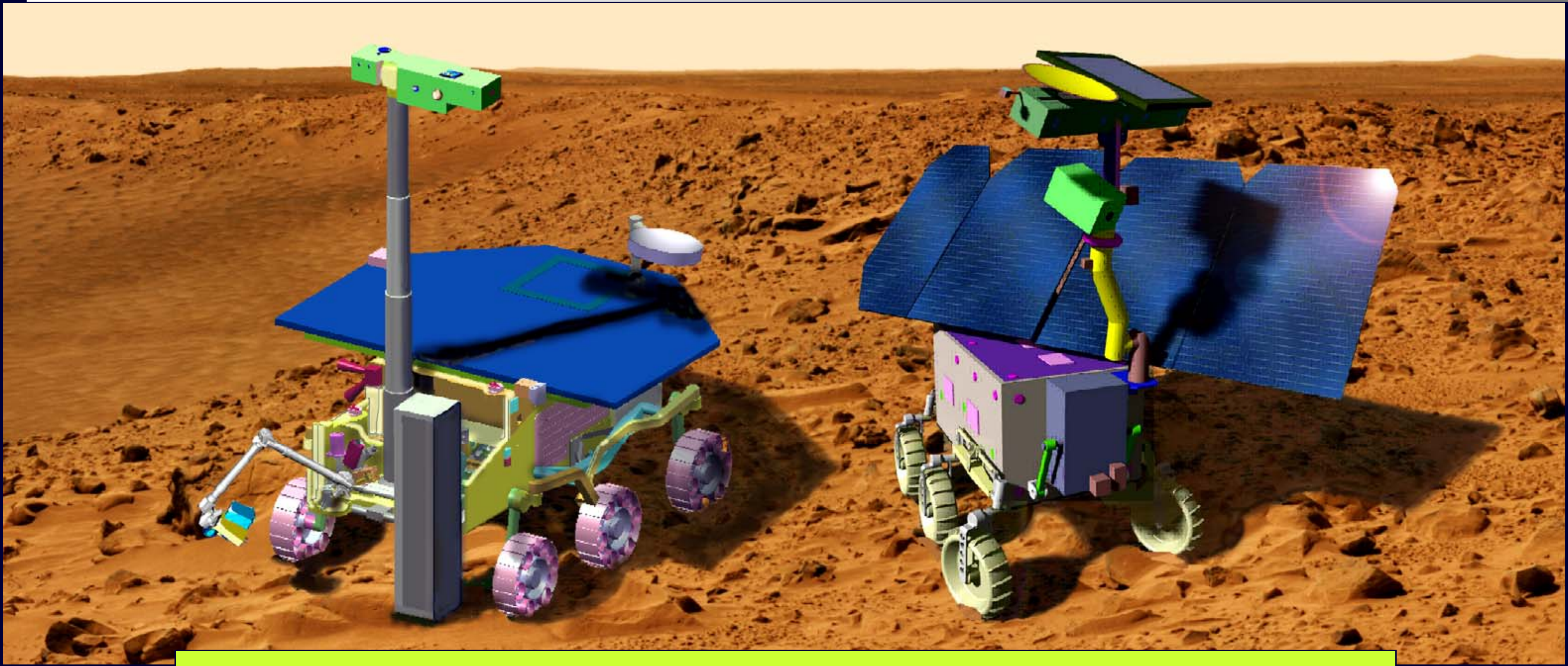
- **ExoMars**: To deploy the first element of the future network:
  - Long lived (>6 yr) station on the ExoMars Lander Platform powered by RTGs.

The GEP payload is still to be confirmed.

GEP could accommodate the Pasteur environment instruments, which do not require mobility, but whose science would benefit from long-term operations:

- Meteorology;
- Dust and water vapour;
- UV;
- Ionising radiation.

Rover mission parameters



• Nominal mission:	180 sols;
• Nominal science:	**10 Experiment Cycles + 2 Vertical Surveys;**
• Extended mission:	10 additional Experiment Cycles;
• Experiment Cycle length:	6 – 18 sols
• Data / Measurement Cycle:	~1 Gbit
• Sandy slopes of up to:	25 deg;

Reference rover mission (1)

a. <u>10 Experiment Cycles</u>: For each EC, the following additional parameters apply for design purposes:

- The "average" distance (path length) between subsequent science locations shall be 1000 m;
- All investigations are performed within a 20-m radius circle, centred at the selected science location;
- Once arrived at the selected science location, perform 1 full-panoramic sweep with the wide-angle, stereoscopic cameras;
- Transmit at least half of the image data to identify targets for contact investigations;
- Conduct a site underground survey using all subsurface sounder instruments (assume measurements are conducted at 4 points, each 10-m apart);
- Obtain infrared spectrometer data and high-resolution images from at least 10 potential surface targets;
- Study 3 different surface targets using the suite of contact instruments;
- Acquire 1 sample from an interesting surface target;
- Perform a complete series of measurements on the collected sample with Pasteur's analytical laboratory;
- Drill and obtain 1 subsurface sample. Assume, on average, a penetration of 1.3 m through loose soil plus 20 cm through well-consolidated deposits (of compressive strength = 60 MPa);
- Perform a complete series of measurements on the collected subsurface sample using Pasteur's analytical laboratory.

Reference rover mission (2)

b. 2 Vertical Surveys:

- **At least twice in the course of the mission, samples shall be obtained, at a single location, from depths of: 0, 50, 100, 150, and 200 cm and analysed with all Pasteur analytical laboratory instruments.**

  The purpose of this is to characterise the soil's geochemical/biological/water/oxidant vertical distribution.

c. Organic cleanliness:

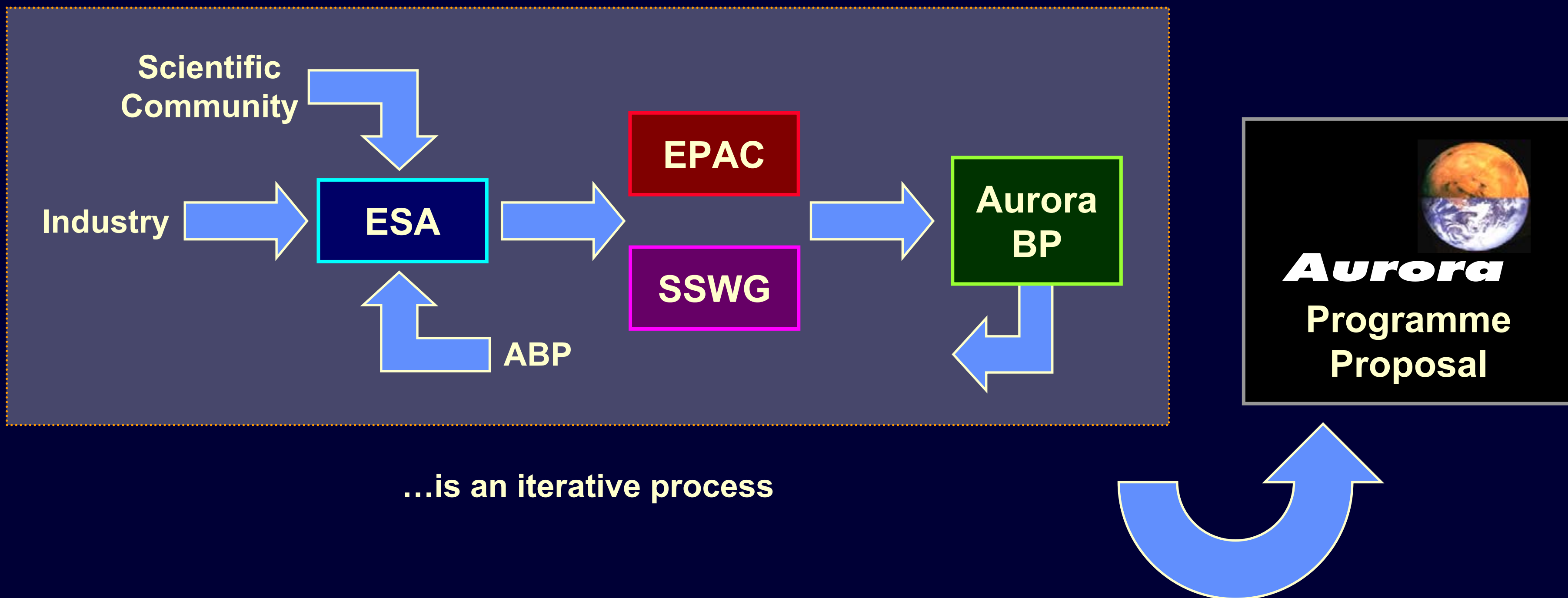
- **Upon landing, the ExoMars Rover shall be able to demonstrate (at least once) that the entire Pasteur sample collection, processing, distribution, and measuring chain is free from Earth contamination.**
- **Upon landing, the ExoMars Rover shall be able to determine (at least once) the level of cross-contamination between samples.**
- **The maximum admissible cross-contamination between subsequent samples is 1%.**

d. Science data volume:

- **The science data generated during an Experiment Cycle shall be at least 1 Gbit;**
- **The science data generated during a Vertical Survey shall be at least 2 Gbit;**
- **The "average" science data generated per day shall be at least 150 Mbit.**

Where are we today?

ESA is preparing the Aurora programme proposal for the Berlin Ministerial Conference.



…is an iterative process

Programmatic constraints

Financial: The ABP has requested that the cost of ExoMars be capped at 600 M€.

Process:

- The launcher must be a Soyuz → No orbiter → ~~Orbital science~~ ~~Data relay~~
- The instruments must be “contributed,” including GEP.
- Reduce the Rover → Pasteur instrument mass: 

  Rover total mass: 120 kg

Rover retains the subsurface drill (from 0 to 2 m depth) → A guarantee to open a new Chapter in Mars exploration!

Technical possibilities

The baseline mission has a 120-kg Rover with 8 kg for Pasteur instruments.

However:

- **It is technically possible to accommodate a ~170 kg Rover, with more Pasteur instruments.**

→ **Higher mission cost.**

The additional cost needs to be justified with a strong science case.

Pasteur WG #2 Meeting objectives

1. To inform the Pasteur and GEP scientific communities of the present development status of the ExoMars mission.

2. To define, with representatives of the identified Pasteur and GEP candidate instruments, a strategy to achieve the ExoMars mission objectives with the available resources.

3. To consolidate the mission's scientific aspects (integrate Rover and GEP science).

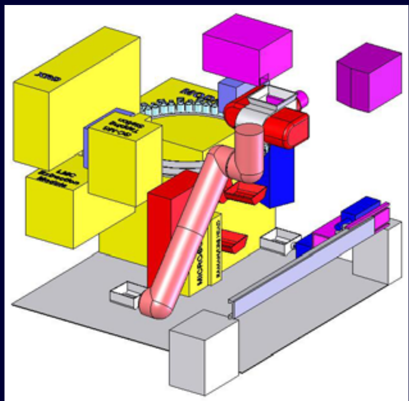
4. To identify measurement and instrument priorities:
   - for the baseline mission design: Pasteur 8 kg + GEP 5 kg;
   - for a possible Pasteur instrument mass allocation up to 14 kg + GEP 5 kg;

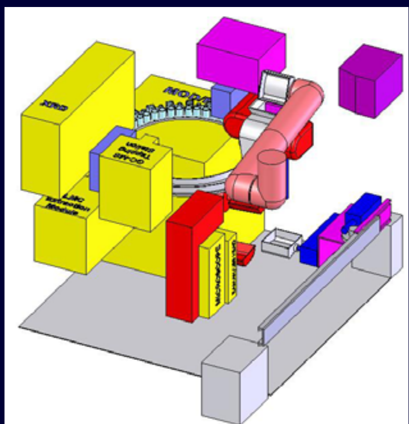
5. To draft recommendations, regarding the instrument composition for the Pasteur and GEP payloads, to be used to prepare a presentation to the ESA Advisory Bodies (EPAC & SSWG) and to the Aurora BP.

Meeting Organisation

1st DAY:	Morning:	Presentations			
	Afternoon:	Working Groups:			
		Measurement priorities	Search for Life	Geological Context	Geophysics Environment
2nd DAY:	Whole	Instrument composition	Search for Life	Geological Context	Geophysics Environment
3rd DAY:	Morning:	All: Conclusions, draft inputs for presentations, AOB.			

Pasteur payload evolution





Estimated Pasteur instrument mass: ~~24~~ kg

12.5

Remote

Contact Suite

Analytical Lab.

CONTEXT

PanCam
IR Spectr.
GPR
Neutron Scatt.
Close-up Imager
Mössbauer
APXS
Raman & LIBS
Microscope IR
XRD

ORGANICS/LIFE

MOD/MOI
GC-MS
Life Marker Chip

ENVIRONMENT

Dust & H_2O
Ionising Rad.
UV Rad.
P, T, Wind

Accommodated in GEP

SUPPORT INSTRUMENTS

Drill System
(2-m depth & surface)
incl. Borehole IR

Manipulator Arm

Sample Preparation &
Distribution System

Conclusions

Noting that:

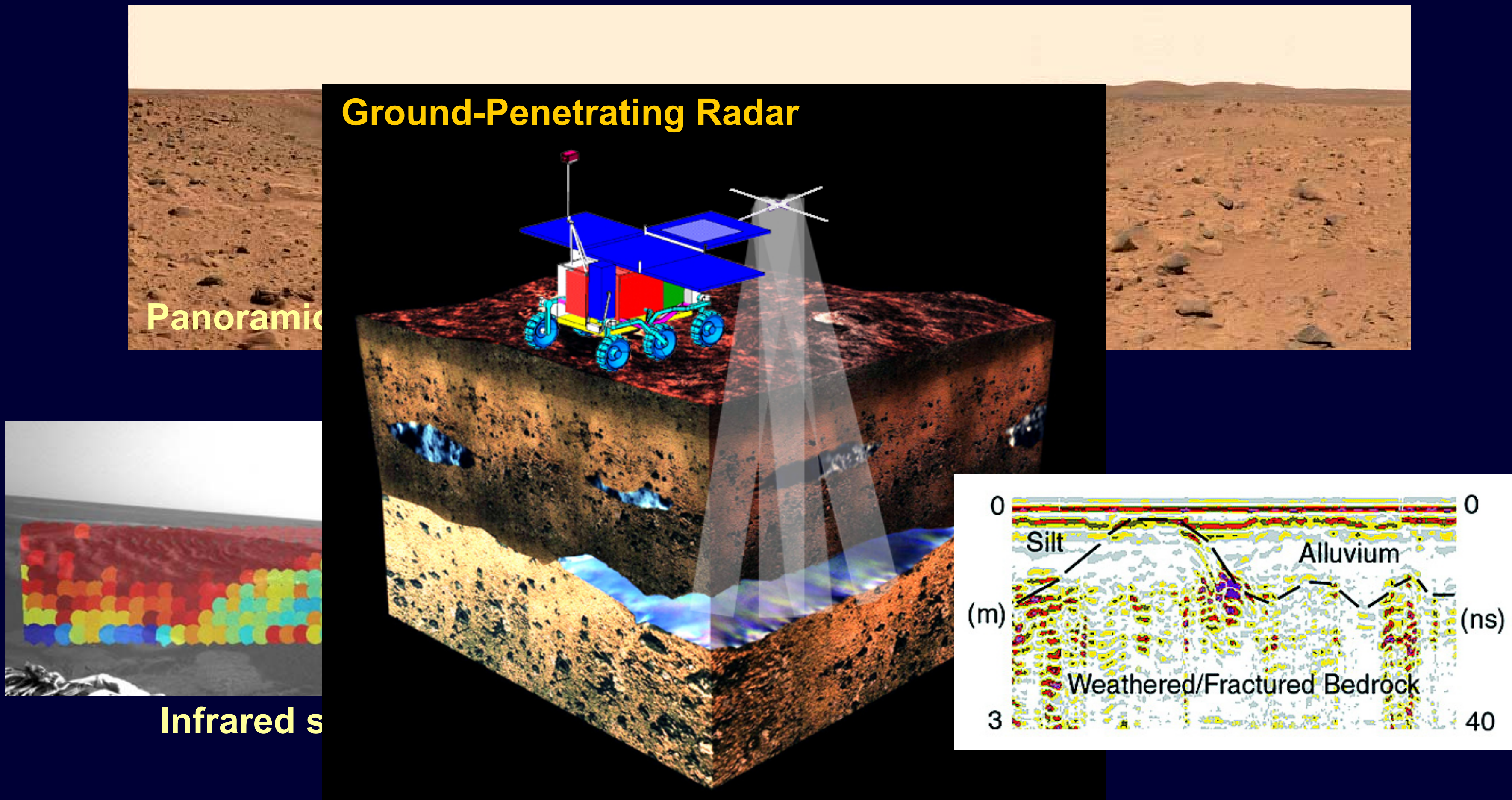
ExoMars, with its subsurface drill, will provide a unique opportunity to effectively search for life on Mars.

The participants recommended:

- A 12.5-kg rover payload considered the minimum to do the job properly.
- To include the Pasteur environment package in ExoMars.
- To confirm the implementation of the GEP station in the mission.

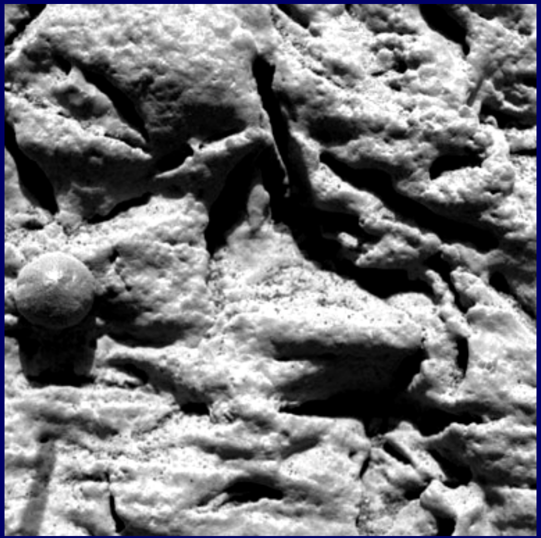
Site characterisation

AT PANORAMIC SCALE: Establish the geological context



Contact instruments

AT ROCK SCALE: To ascertain the past presence of water;
For a more detailed geochemical and morphological examination;



- Close-up imager
- Mössbauer spectrometer
- Raman/LIBS optical heads

If results are interesting, obtain a core sample:

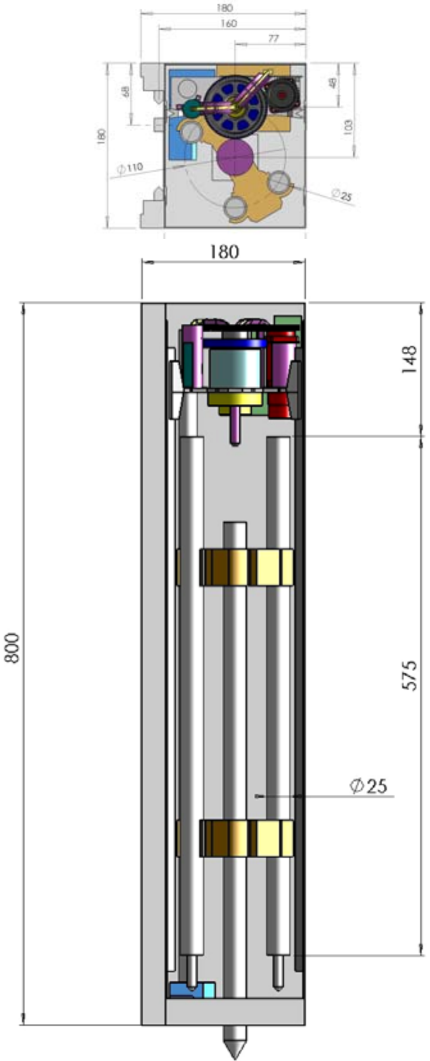
Underground
Surface rock

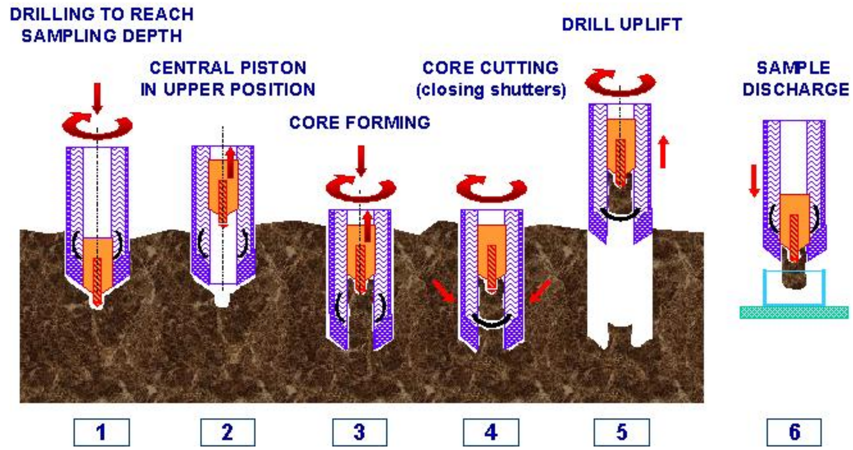
using the Pasteur drill.

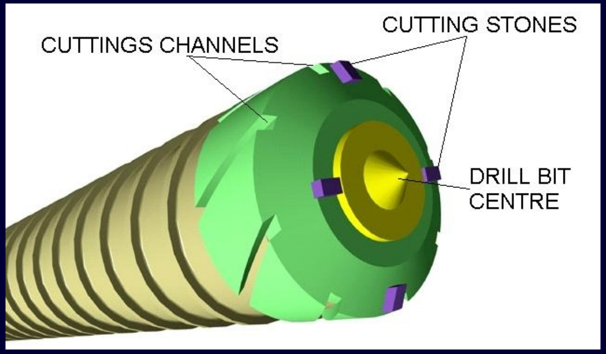
Support instruments

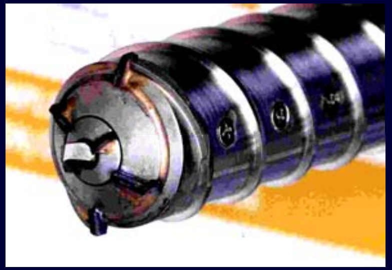
DRILL SYSTEM: Obtain samples for analysis;

SPDS: Prepare and present samples to all instruments in analytical laboratory.



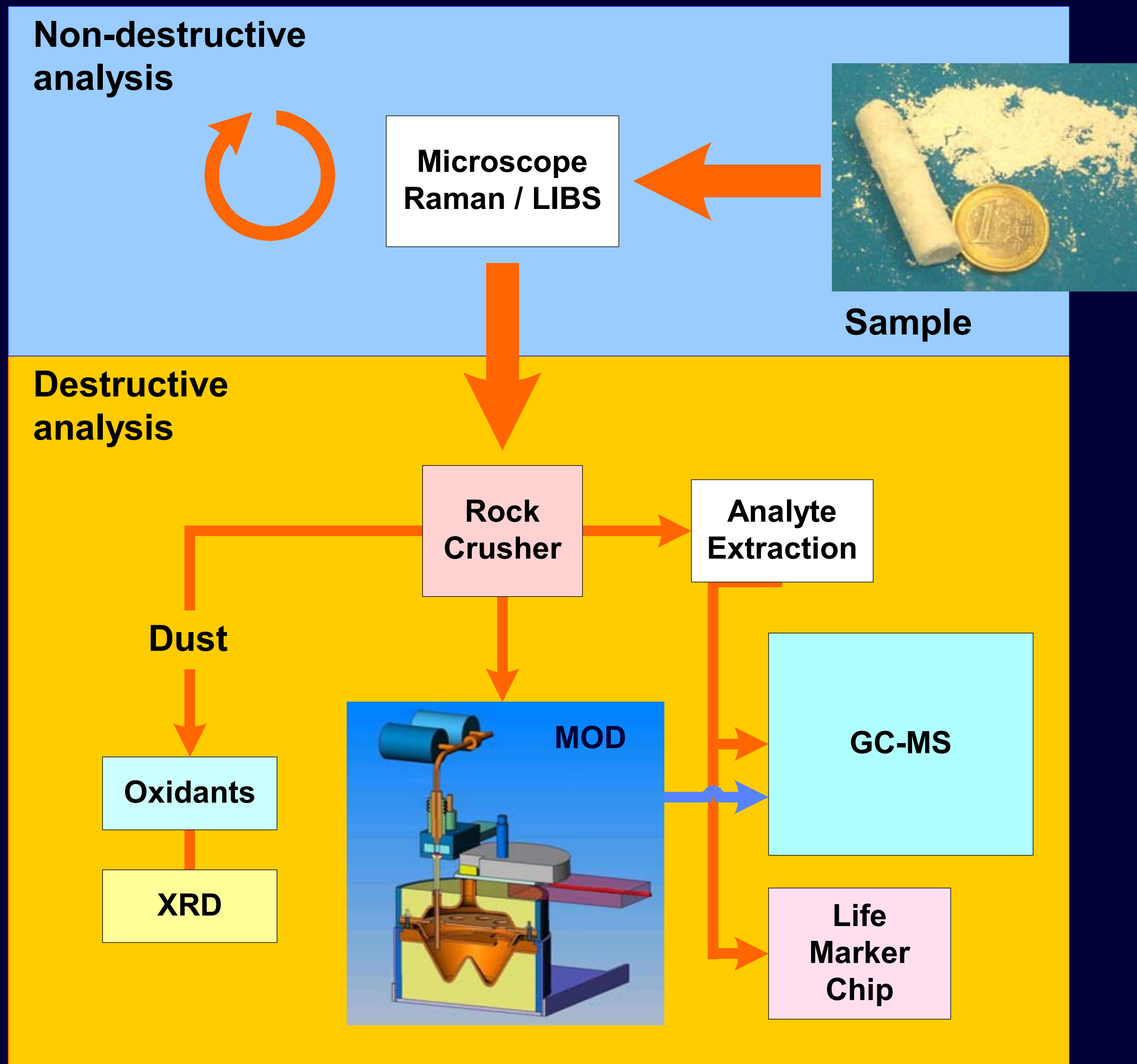






Subsurface drill includes miniaturised IR spectrometer for borehole investigations.

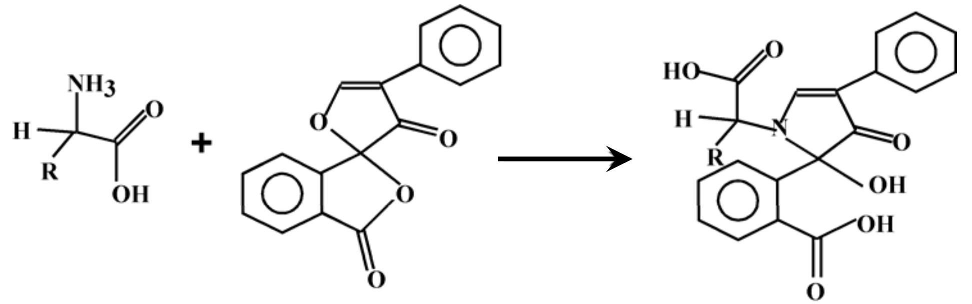
Analytical laboratory



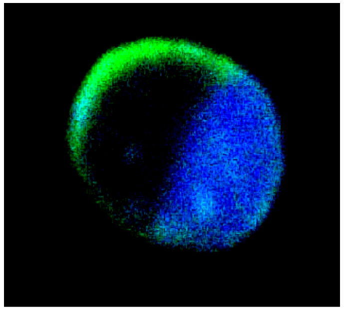
<u>Nominal mission</u>:

10 surface +
20 subsurface
samples

Mars Organic Detector (MOD)

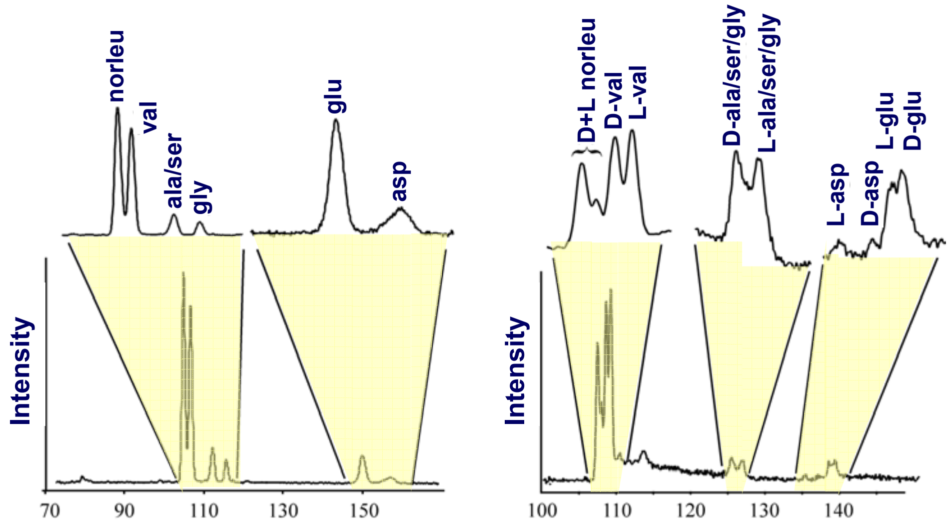


Amino acid Fluorescamine Derivatisation



Concentration

Laser-Induced Fluorescence (LIF) indicates if the amino group is present



Composition Enantiomeric proportion

µCE to evaluate composition and enantiomeric excess

Hazards, environment, and meteorology

Dust measurements

- Size distribution and deposition rate;
- Impacting dust devils: direction, speed, spatial and temporal scales, effects.

Ionizing & UV radiation

- Spectrum, absorbed dose, quality factor, dose equivalent.

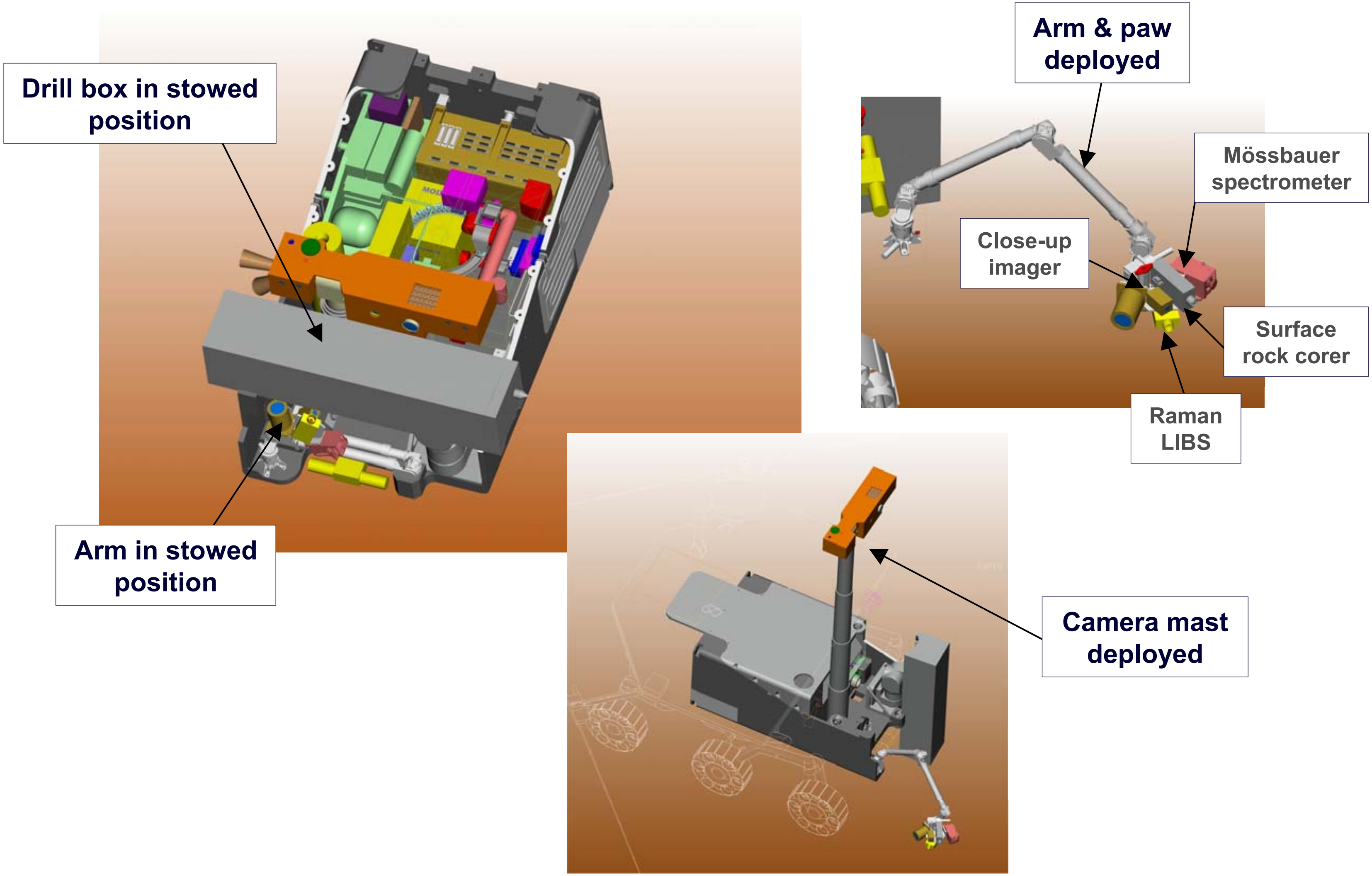
Reactive substances in the subsurface and atmosphere

- Oxidant identification and reactivity;
- Subsurface vertical distribution, extinction depth, diffusion laws;
- Coupling between oxidants and UV radiation.

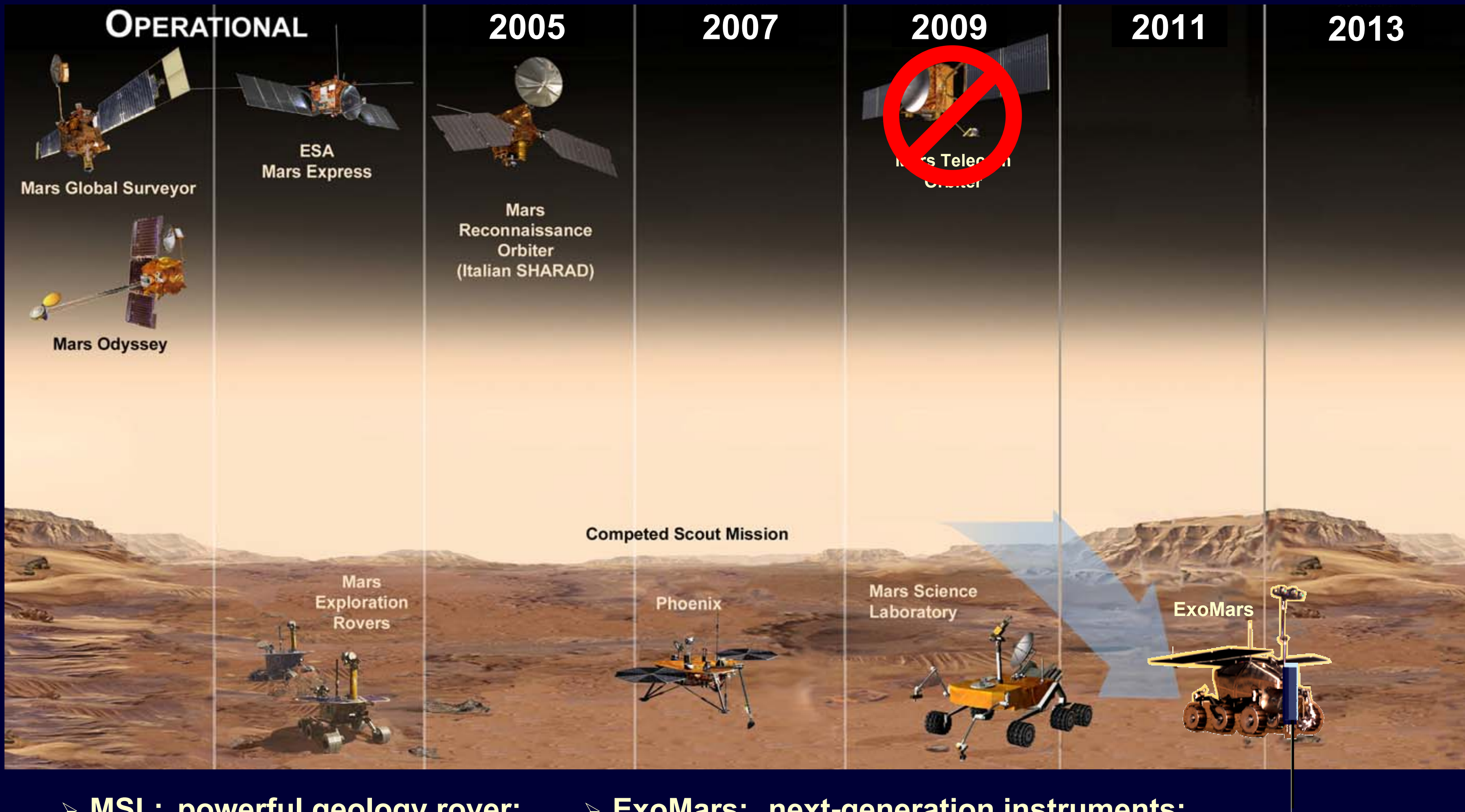
Local climate & meteorology

- Temperature;
- Pressure;
- Humidity;
- Ice condensation.

Pasteur Phase A configuration



The international context



- MSL: powerful geology rover; large 2-D mobility.
- ExoMars: next-generation instruments; 3-D mobility.

Following on the results of MSL, ExoMars is the logical next step in international Mars surface exploration.

ExoMars applications for future missions

- The next important mission will be an international Mars Sample Return effort;
- A possible ESA contribution could be an ExoMars-class rover, with its drill, to collect the samples, seal them, and pass them on to the Mars Ascent Vehicle;
- This would grant Europe a long-term horizon to develop an ExoMars-derived capability in autonomous rover systems, drilling, sample preparation & sealing, and planetary protection;
- Additionally, the Pasteur payload —with its next-generation scientific instruments— will contribute to numerous future planetary robotic missions;
- The Pasteur instruments will result in multiple terrestrial applications, in fields such as forensic analysis, environmental monitoring, and portable instrumentation;
- ExoMars technologies will also prove useful for future human exploration missions, including the ISS, the Moon and Mars.

Conclusions

- ExoMars is a timely and exciting European and international mission.
- ExoMars will be the first Mars mission ever to combine mobility and access to the subsurface.

  Its Pasteur payload is designed to study, for the first time:
  - Organic compounds and biomarkers for past and present life;
  - Vertical distribution profiles for geochemical composition and water;
  - Reactive chemical species (oxidants) on the ground and atmosphere.

- ExoMars will deliver the first element of a new international geophysics / environment network to the Martian surface.
- ExoMars provides an excellent base to collaborate in future international Mars missions.