LONG LIVED MARTIAN GEOSCIENCE OBSERVATORY

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Abstract

If the apparition of life is maybe a rapid process on a habitable planet, the evolution of life toward intelligence is a much longer process and about 4000 Myears were needed on the Earth. What is the probability for a telluric planet to offer the right conditions to life evolution? Why is the Earth the only planet on the Solar System where liquid water was able to be maintained liquid at the surface, and why Mars and Venus were unable to maintain such temperature conditions? What is the level of volcanic activity on Mars? What is the heat flow and its impact on the temperature gradient in the subsurface? How can we extrapolate this activity in the past and estimate the importance of volcanic degazing and its impact on the early atmosphere?

Do we have indications for an early plate tectonics regime on Mars with a water rich upper mantle and how important is such a regime in the habitability of planets? Why and when stopped the Martian dynamo? All these scientific questions, which impact on the Martian long term habitability, are related to the geodynamics of the planet and its geological evolution and activity. In order to provide an answer, we need to understand how a telluric planet is geologically evolving, which needs a detailed knowledge of its interior structure, of the mineralogy and temperature of its mantle, of the amount of energy released during accretion and therefore of the size of the main units of the planet (crust, mantle, core), of the heat flux and possibly of the long scale convective structure. We also need to monitor its present geological activity. The Long Lived Geoscience Observatory on Mars will setup a permanent network of fixed stations on the planet, operating for a decade or more. These stations will monitor with high resolution the magnetic field, the rotation and the seismic activity of the planets, will measure the heat flux and will in addition monitor the present environment (meteorology, radiations, ionospheric properties, etc) and support human exploration. This suite of instrument will be able to perform a passive sounding of the deep and shallow planetary interior and to retrieve the temperature profile and mineralogical profile in the planet and 3D mantle lateral variation by a joint inversion of the seismic, conductivity profiles and heat flux and geodetic data. 8 stations, operating for 4 to 10 years will be necessary to obtain such detailed tomographic picture of the mantle convection and we can therefore expect a full deployment after 4 or 5 Mars windows. Such stations, comparable to the of Autonomous Lunar Surface Experiment Package, deployed by NASA during the Apollo missions, might be deployed systematically by all the future Mars landing missions and might therefore be an original European contribution to the International Mars exploration in the next decade and will complement with the necessary geophysical data the analysis of the future sample return missions. In addition to Roving and Sample Return mission, they also can be deployed by more dedicated multilander missions. In addition, such stations might also be proposed to the future Moon landing missions. In both cases, these Planetary Long Lived Observatories will not only help us to better understand the formation and evolution of two of the Solar Systems Terrestrial Planets, but will also support human exploration by a permanent survey of the planetary environment.

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1. Introduction

Mars probably was a planet with a dense atmosphere, a magnetic field and with liquid water flowing on its surface at a time where life appeared on Earth. The planet at the time likely offered conditions comparable to the Earth to harbour life. But today, Mars has lost its atmosphere, magnetic field and only water ice remains at (or underneath) the surface in the regolith. The example of Mars suggests that if life appeared on a planet its persistence and evolution over billions of years depends on the geological evolution, including the magnetic field, the volatile inventory, and on atmosphere and tectonic history.

The main scientific goal of the European Martian Long Lived Surface Packages will be to provide the key geophysical parameters necessary to constraint and understand the formation and geodynamical evolution of the planet, to better understand the past and long term habitability of the planet and the atmosphere interior coupling and to characterize and monitor its present environment. We present in this paper the science objectives a network of Long Lived Surface package on Mars as well as a model payload of the package. We briefly present also the other opportunities for deployment of such package on the Moon.

2. Science Objectives

The science objectives of the Long Lived Martian observatory are related to the understanding of the formation of planets, to the long term habitability of these planets (over billions of years) and to the present environement and habitability.

Understanding the formation of the planet and constraining the early Mars conditions.

The most recent analyses of SNC meteorites have provided key constraints on the timing of the Martian formation and are pointing toward a rapid differentiation probably associated to a global silicate magma ocean resulting from the accretion heating: the isotopic record in the SNC meteorites (in particular Hf/W) suggests that core formation occurred during or soon after accretion in about a few 10 Ma and that a primary crust was likely produced during that time and in the following few 100 Ma [Solomon et al., 2005], parts of which may still be present in the southern hemisphere [Wieczoreck and Zuber, 2004].

But although the variation of the thickness of the crust across the entire planet is constrained by gravity data (Zuber et al., 2000, Zuber, 2001), its absolute thickness is poorly known and the size of the core is also poorly constrained by geodetical observations. The mean composition of the planet, and therefore the mean composition of the building rocks remains however unknown and various of the geochemical models [Dreibus and Waenke, 1985, Longhi et al., 1992, Sanloup et al., 1999, Verhoeven et al., 2005] can explain the observed value of the moment of inertia factor together with a (partly?) liquid Martian core, as is suggested by the MGS tracking data (Yoder et al., 2003). The initial mean temperature and heat flux are also poorly constrained by the presently returned data [Solomon et al., 2005], leading to large uncertainties in the early Mars conditions, especially in terms of subsurface temperature conditions and possible hydrothermal activities.

Together with the relative datation of the volcanic history by MarsExpress, the estimation of the radiogenic content of the crust by Mars Odyssey, and the analysis of SNCs, a determination of the dimensions and masses of the major Martian chemical reservoirs (crust, mantle and core) and of the present heat flux will contribute to a better understanding of planetary formation in general but also of the early Mars geology and environmental conditions.

Constraining the Martian geological history and understanding the long term habitability of telluric planets

The post-accretion evolution of a terrestrial planet is mainly governed by the strength of the convection in its interior. Such activity is necessary to maintain volcanism and a magnetic field during billions of years. The Earth, thanks to plate tectonics, has moreover been able to maintain a stable and habitable atmosphere. Recent modelling has shown that this geological activity depends to a large extent on interior structure, in particular on core size, on depth of major phase transitions in the mantle, and on the thermal lithosphere thickness. Since Mars is in between the small and the large planets satellites it offers a unique chance for understanding the terrestrial planets in general. The evolution is manifested in surface tectonic features, in the vigor of volcanic and seismic activity, in the composition of surface rocks, its atmosphere and hydrosphere, and in the history of its magnetic field.

For example, the huge shield volcanoes in the Tharsis area imply a strong mantle plume of large radial extent beneath this region. The most recent data of Mars Express, such as methane detection [Formisano et al, 2004], young caldera activities and very young flank activities [Hauber et al, 2005], as well as gravity topography analysis [Belleguic et al., 2005] suggest an upper mantle possibly hot enough to maintain plumes or a zone of partial melting.

What is the driver of Martian convection? Convection models [Harder and Christensen, 1996] suggest that a single strong plume may be initiated after some time by the interaction of mantle flow with mantle phase transitions [Breuer et al., 1998]. A particularly important transition is the one from spinel to perovskite that characterizes the transition from the upper to the lower mantle on Earth and that may occur just above the core mantle boundary in Mars. The models suggest that this transition, of which the presence is debated, may be important not only for plumes and associated surface volcanism but also for the evolution of the core and the magnetic field. The magnetic observations made onboard Mars Global Surveyor have demonstrated that an active dynamo existed at the beginning of the life of the planet, but then became extinct. This constitutes a new constraint on the planets evolution.

There are various paths of evolution of the dynamo consistent with the observations, but they would leave the core either completely solid or liquid. A confirmation of the present state of the outer core and characterization of the presence or absence of a solid inner core from seismic data would strongly constrain the evolution and would have implications for the evolution of the cores of the other terrestrial planets. By determining the core radius the presence of a perovskite layer can be confirmed or rejected. In conjunction with the total mass and moment of inertia of the planet, knowledge of the core radius allows to constrain the concentration of a light alloying element in the core (probably sulphur), which has implications for theories of planetary formation.

While interior structure largely sets the stage for how the mantle may flow and transfer mass and heat, the energy balance of the interior is manifested in the surface heat flow. Surface heat flow can be measured by determining the near surface temperature profile and the thermal conductivity. All this information will help us in understanding planetary evolution and hopefully, will allow us to understand better how a planet can start and then stop plate tectonics or never start it (e.g. Breuer and Spohn, 2003). Knowing and understanding the planetary and atmospheric evolution will therefore give us a new view on the planetary habitability and therefore on the probability to find, in the universe, other planets providing, during billions years and like the Earth, conditions compatible with life.

Understanding the present environment and its coupling with the planetary history

The interest in Mars and its atmosphere stems fundamentally from the fact that Mars is at the same time very Earth-like, but has important differences from Earth (Zurek, 1992). The rotation rates and inclinations of the rotational axes of Mars and the Earth are very similar, implying similar dynamic features and seasonal variations. Both planets have an atmosphere that allows a substantial fraction of the incoming solar radiation to reach the surface. In a globally and annually averaged sense the fraction absorbed by the atmosphere is approximately 34-41 % for the Earth atmosphere system. For the Mars atmosphere system the same fraction is of the order of 8 % (background dust load, visible wavelength optical thickness f about 0.3) to 20 % or more (f larger than 1.0). The atmospheres of both planets are hence to a substantial degree heated by a combination of indirect surface heating (through convective mechanisms and thermal radiation) and secondarily by direct absorption of sunlight.

Among the key differences are Mars different orbit (larger distance from the Sun, resulting in lower solar insolation and higher orbital eccentricity), as well as atmospheric composition and thickness and a relatively larger mass exchange between the atmosphere and the surface and polar caps. The combination of similarities and differences between Earth and Mars makes Mars an ideal laboratory for comparative studies of the circulation phenomena and climates of small solid planets with high rotation rates and differentially heated atmospheres.

In addition to the intriguing contemporary characteristics, Mars and its atmosphere have clearly had an interesting early history and subsequent evolution, but the nature thereof remains unresolved (Fanale et al., 1992). The evidence regarding the nature of Mars early atmosphere is at best inconclusive. Orbital imagery shows apparent ancient shorelines, outflow channels, and valley networks. Such formations have been created by either hydrological cycles made possible by a period or periods of warmer and thicker atmosphere allowing for liquid water to exist on the surface or by catastrophic releases of groundwater to the surface.

The later scenario is possible even in a thin and dry climate, as a catastrophic release of groundwater has probably been associated with a cometary or meteoritic impact resulting in melting of the permafrost. The first scenario or long-term warm and wet atmosphere may have been possible through long-duration volcanic supply of CO2 into the atmosphere, but shorter-duration conditions for at least local hydrological cycles may have also been created by episodic volcanic pulses of CO_2 as postulated by, e.g., Baker et al. (1991) and Gulick et al. (1997). In both cases the dwindling of the CO_2 supply would have resulted in the reduction of pressure and cessation of conditions favourable to liquid water on the surface, due to CO_2 outgassing, formation of carbonates, and absorption into the regolith.

Nor does other evidence, such as the ratios of $_{15}$N, $_{14}$N, heavy oxygen to oxygen, and D to H, allow one to draw firm conclusions regarding the characteristics of Mars past atmosphere (Owen, 1992). In addition to the possible transition from an early thick and warm atmosphere to the current conditions, the atmosphere has experienced nearly cyclic variations due to quasi-periodic changes in the planets orbital and rotational parameters. The variations of orbital eccentricity and axial tilt occur in time scales of the order of 10^5 to 10^6 years for Mars and 10^4 to 10^5 years for Earth.

These variations are believed to control the timing of the terrestrial ice ages through changes in the distribution of solar heating and hence in the circulation; due to the larger variations in Mars astronomical parameters the effects should be more pronounced for Mars than for Earth and on Mars include modifications in the dust and volatile cycles. Evidence for a periodic or quasi-periodic component in the Martian climate is seen in the layered terrain in the polar regions (Milkovich and J. W. Head III 2005), Changes in the Martian atmospheric conditions and especially the likelihood of liquid surface water in the past are intimately tied with the possibility of biological evolution and either occurrence or existence of life on Mars in the past and present.

Preparing the future of Human exploration

Human exploration of Mars is foreseen around 2030 and the preparation of such exploration is one of the major goals of the Euroean and US exploration programs. However, very little is still known on the resources of the planet, especially water, and on the environment.

Access to the Martian subsurface will be therefore a key objective of the future ten next years in the exploration of Mars. The discovery and understanding of geologic processes which have been active during the formation and evolution of the planet are one of the major objectives of the exploratory missions to be launched to Mars in the coming years, especially in a follow the water strategy (with a focus on all processes associated to water). Owing to the stability of the planetary crust, the subsurface, down to a depth of 2 km, represents a region of great interest since its structure and the embedded geomorphological entities must reveal the main characteristics of volcanic and sedimentation processes. However, the most important objective remains probably:

- The search for sedimentary layers. Recent results strengthen the occurrence of persistent lakes on early Mars, such as the confirmation of possible delta (Malin and Edgett, 2003), or possible aqueous deposits in Terra Meridiani. The preliminary results of the Opportunity rover, with the discovery of possible sedimentary rocks, excavated in an impact crater, are probably the first example of an in-situ analysis of sedimentary rocks on another planet than Earth. But Gusev was supposed to be an ancient lake and rocks analyzed by Spirit at the surface consist of lavas. Sediments could be 10 meters underneath lavas, but it is still unknown where one would be able to access them. These two examples show that sedimentary layers are probably located under dust and volcanic layers, formed after the end of a warm and wet epoch on Mars.
- The search for ground reservoirs of water, either as ice or as liquid water. This question is essential to understand the long-term evolution of the atmosphere of the planet and of its climate. It will be also a key parameter for defining the infrastructure of a human presence on Mars. It is supposed that a large quantity of volatiles still reside on Mars. This water might still be concentrated in the Martian regolith as clay mineral (constitution water), and as underground ice. With a mean annual temperature of -60^{o}C and a dry periglacialtype climate, Martian permafrost should be stable at some depth over virtually the entire planet. Theoretical estimates of the permafrost thickness range from 3 to 7 km near the poles to between 1 and 3 km near the equator (Fanale et al., 1986). Liquid water should exist under the ground ice, at least at middle latitudes. The depth to the top of the ice layer and the transition depth from ground ice to liquid water appear to have had significant effects on the morphology of surface features (e.g., outflow channels, rampart craters, terrain softening).

-The determination of the porosity profile in depth. Such parameter is important to determine the amount of water possibly stored in the Martian subsurface, but is also an important parameter to locate subsurface area where a biologic development was either possible.

Martian meteorology and atmospheric dynamics hazards will be another major concern for future human mission. The state of the atmosphere, its vertical extension and the vertical profile of density, dust and wind is indeed a major parameter for the entry phase of future landers, as well as for possible orbiters using aerocapture techniques. But on the ground, the structure and dynamics of planetary atmospheres are significantly affected by electrical phenomena. This is very clear on the Earth where the creation and transport of electrical charges (in particular on hydrometeors), the dynamics of electrified clouds and thunderstorms have a major influence on long-term climatic variations. In the lower atmosphere of Mars, large electric fields can develop and probably lead to electrical breakdowns. This can cause noticeable effects on the dynamics of the atmosphere and dust particles, and on physical and chemical processes at the surface. There exist indeed a variety of charging mechanisms of which the efficiencies are enhanced by some characteristics of the Martian atmosphere such as low pressure and chemical composition (CO_2 being the dominant constituent). For example, one can mention photoelectric effects on the surface material, the transport of photoelectrons (Grard, 1995) and, more, especially charging mechanisms associated with the triboelectric effect of winds and dust impacts in a very dry atmosphere. These effects might affect future human missions, especially EVA and telecommunications and must be studied before.

3. MISSION SCENARIO AND LIFE TIME

The ML2SP network will be based on a Long Term power source. Future planetary observatories indeed will require such a long operation (i.e. 6 or more years). Such operation is comparable to the Apollo ALSEP network, which was able to operate for 7 years seismometers, magnetometers and solar wind sensors. It can be compared also to the Viking 2 Martian years (i.e. 4 years) of operation. The ML2SP will be, for Europe, the Pathfinder mission for developing such power source and will be the first step in an ambitious program for the development of European

RTGs and RHUs allowing to the future cosmic vision program to explore the far solar system.

The deployment goal of the ML2SP will be a progressive and continuous deployment over the 2010-2020 decade. The first opportunity will be the AURORA 2011 mission. The other opportunities will be during the cosmic vision time frame and the post-2011 AURORA mission, as well as by the future missions of the US Mars exloration program, such as the NASA 2011 SCOUT and possibly all other NASA mission later than 2011. The ultimate goal of the ML2SP is therefore to setup a network of Observatories, a science objective recommended consistently and repeatedly over the last decade by European, US advisory groups, as well as by the International Mars Exploration Working Group (IMEWG) and several Academies of Science.

Major scientific results will however be returned by the first station. Viking seismometers [Anderson et al., 1977] provided only a loose upper bound on the seismic activity of the planet [Goins & Lazarewicz, 1979], which could still be several orders of magnitude more active than the Moon. Thus we have no firm idea as to the size, frequency, distribution, or signal characteristics of Martian seismic events, or of the character of any seismic noise. The first seismometer will therefore not only characterize the seismic activity and confirm a possibly present activity of the planet, suggested by the most recent Mars Express data, but will also constraint the crustal thickness below the landing site, the lithosphere thickness with surface wave dispersion and, with a long term operation, might record large quakes strong enough to excite free oscillations well above the seismic/instrument noise (see Lognonné et al., 2000 and Lognonné, 2005 for more detailed science objectives). Geodetic measurements (e.g. Dehant et al., 2000) will complement the seismic data by providing improved constraints on the density of the planet, including the density jump between the core and mantle by the first measurements of the free core nutations.

Magnetometer, heat flux and electric field sensors will provide measurements never performed at the surface of Mars and have detailed science objectives described in Menvielle et al. [2000], Berthelier et al. [2000]. Together with the Mars Odyssey GRS data and SNC analysis, the heat flux data will allow the estimation of the amount of heat released from radioactive elements and from the cooling of the accretional heat. Such measurement will strongly benefit from a Long Term operation, enabling the separation of the temperature gradient from heat flux to the yearly signal. Together with the seismometer, the magnetometer will constraint the upper mantle temperature through a measurement of the mantle conductivity, using models of interaction between the solar wind and the planetary environment for the first ML2SP. A more constrained one will be used when several packages will be deployed.

The atmospheric package will, for the first time since Viking, perform atmospheric measurements during more than one Martian year. Such measurements will, in addition to the geodetic measurement of the variation of Length of Day (LOD), constraint the global circulation and atmosphere polar cap exchanges. A focus will also be done on meso-scale measurements, with a detailed monitoring of the dust cycle, with optical depth, electric field and wind measurements. Finally, the radioscience (in the full payload) will provide a determination of Mars orientation in space from which precession, nutation, and length-of-day variations can be obtained. The observation of these phenomena will allow us to obtain information on the moment of inertia of the planet as well as on the state and dimension of the core.

4. Network deployment and scientific return

Although an optimal configuration of the Mars Long-Lived Stations needs 4 or more stations to ensure the complete scientific return of a network, a dramatic increase in Mars science can be expected from the deployment of the first stations.

We give here three examples mainly related to the geophysical part of the payload:

The first example is seismology and heat flux: the heat flux was never determined on Mars and very large uncertainties remains on the heat flux value, a key data to understand the present cooling rate of the planet . The same is true for seismology and the seismic activity is still unknown, with only theoretical estimates based on the thermo-elastic cooling of the lithosphere or on fault counting (e.g. Golombek et al., 1992). It will be constrained by searching for events with the permanent operation of the seismometer. The analysis of the data gathered by these two instruments will therefore help us to answer to the following questions: are Martian volcanoes active today? What is the thermoelastic cooling of the Lithosphere?

Concerning the interior determination, the science return will increase with the number of stations but also with the duration of operation and a significant return will be achieved by the long term operation of the first station. Indeed, the Martian activity is expected to release a cumulated activity of 10^{18}-10^{19} Nm per year, leaving statistically the possibility to detect magnitude greater than 5 with a recurrence time of one Martian year. Such events will excite free oscillations of the planet to an observable level (Lognonné et al., 1996, Gudkova and Zharkov, 2004). The same will be true for geodesy, where time is compensating the lack of data due to a limited number of landers (Yseboodt et al., 2003) and more precise measurements of the Love number and inertia factors will be done. In both cases therefore, the long term operation of the data will lead to data enabling the determination of the deep interior, while the crustal structure will be obtained by receiver functions analysis (Vinnick et al., 2001).

The deployment of the other stations will progressively increase the interior models and will also provide new information on lateral variations. With two stations, a rough determination of the upper mantle and crust structure with 5-10 % error determinations instead of a few % with travel time analysis could be possible .

When 4 stations or more will be deployed, a much better resolution will be achieved with travel time analysis. A detailled analysis (Mocquet, 1998), shows that a rate of 60 % can be achieved for the detection of quakes with seismic moment greater than 10^{14} Nm, i.e., corresponding to Earth magnitude greater than 3.2. This might provide about 100 detected quakes out from the 140 quakes expected during an Martian year. Note that a 4 stations network configuration, in contrary to the Moon seismic network, will allow a much better characterisation of the core, as soon as an observatory is deloyed at the antipode of the three others. With a 5th station, the gap of coverage will be covered: If a 4 station network is able to detect the direct P and S waves generated by quakes, distributed globally on Mars, with an efficiency of 61%, a 5 observatory network can achieve an efficiency up to 90 %.

5. Model Payload for a Martian Package

While other Mars missions are focusing on exobiology, surface mineralogy and atmosphere composition, the ML2SP package will perform the novel and original long-term geophysical and environmental measurements. The Long Live geophysical network will therefore have a core payload based on a 3 axis ultra-sensitive very broad band seismometers, an heat flux package with a deep deployment capacity, an ultra-precise geodetic beacon and radio-science system, an ultra-sensitive fluxgate magnetometer and a complete environment integrated payload (pressure, temperature, humidity, wind, optical depth, electric field, UV flux, radiation). In addition, subsurface experiments, which might operate in bi-static mode with the lander carrying the package can be considered, in order to perform soundings of the subsurface and crust. Ground Penetrating Radar and Short Period seismic sensors can therefore be considered for these subsurface sounding.

In order to reduce the mass of the payload, a strong integration of the payload will be necessary and a central unit for payload acquisition and management will be needed. Most of the payload is mature enough for a rapid implementation and result from technological development associated to previous Mars project, such as the Netlander project. See Dehant et al. 2004 for a more detailed description of possible payload elements.

A payload mass (including margins) of 6 kg, possibly reduced to a 4.5 kg core payload has been considered in a first study and can include most of the instruments listed in Table 1. This assessment study (Biele, Mimoun, Ulamec et al., 2005) has shown that the full mass of the autonomous package, including the complete payload, and bus subsystems (with a 20 %mass margin) is around 20kg.

Table 1. Possible payload elements of a Mars Long Live surface package.

Instrument	Mass (g)	Power (mW)
Seismometer	2000	500
Atmospheric sensors	900	100
Atmospheric Electric Probes	200	100
Radiation sensors	1000	100
Magnetic sensors	300	100
Heat Flow	1500	50
Radio-Science	800	200
Sounding experiments	1000	100

6. Lunar Long Lived Surface Package

In addition, the future Japanese, Chinese and American Lunar exploration programs plan to launch soft landers on the Moon. These missions might offers other opportunities for a Long term Surface Package which will correspond to a new modern version of the Apollo Lunar Surface Experiment Package (ALSEP), deployed by all the Apollo landers. With their long life, they will be the first of a possibly future permanent geophysical and environmental network of the Moon.

Both data constraining the Science of the Moon and the Science from the Moon will be returned by a very similar payload as in the Mars case

Science of the Moon will be first addressed by the seismometer, magnetometer, heat flux measurement and geodesy. The 3 components of the seismometers and their very wide frequency band will indeed partially compensate the lack of other seismic stations, and will still enable localisation of surface or near surface sources. For the deep quakes, which are assumed to release a continuous and periodic seismic activity on fixed epicenter, a joint analysis with the Apollo data will be possible. The seismometer will then allow a long term seismic survey of the moonquakes and meteorites impacts. Particularly, it will provide a unique monitoring of the rare but strongest tectonic High Frequency Teleseismic quakes, and will possibly allow the first measurements of surface waves . With the large frequency band of the seismic data, the study of the Moon core elastic and anelastic structure along the different paths between the seismometer and the deep moonquakes foci will be possible. Finally, magnetic measurements simultaneously at the Moon surface and onboard the orbiter when the Moon is "permed" by a steady geomagnetic tail field should allow to determine the bulk relative magnetic permeability of the Moon

The package will also be able to explore the domain of Science from the Moon. Because the Moon is crossing the far geotail twice per orbit, it will provide a long term monitoring of the Earth geotail and Solar wind with dedicated radiations and particules sensors. The monitoring of the seismic noise (from DC to 50 Hz), will allow to constrain the influence of the moon stability and local meteorites micro-impact on the future Moon based satellites

This shows that many science objectives will be reached with a Lunar version of the package and that a generic approach can be therefore proposed for the development of the subsystems of the Long Lived Package, in order to ensure that a dual use of these systems for a Mars and Lunar mission is possible.

7. Conclusion

We have proposed a scenario for a permanent scientific presence of Europe on Mars and on the Moon along the future decade, based on Long Lived Surface Packages deployed primarily by the future missions of ESA's, NASA's exploration programs, but also by Lunar missions of JAXA and China and all other future science mission to the Moon and Mars.

Such scenario will allow the deployment of geophysical and environmental networks on these terrestrial bodies. By monitoring with high resolution the magnetic field, the rotation and the seismic activity of the Mars and the Moon, and by measuring the heat flux, they will provide us the key missing data for the understanding of the planetary evolution of terrestrial planets. In addition, they will monitor the present environment (meteorology for Mars, radiations, ionospheric properties, etc) and support the future human exploration of the solar system.

8. References

Anderson, D. L., W. F. Miller, G. V. Latham, Y. Nakamura, M. N. Toksoz, A. M. Dainty, F. K. Duennebier, A. R. Lazarewicz, R. L. Kowach, and T. C. Knight, 1977, Seismology on Mars, J. Geophys. Res., 82, 4524-4546

Baker, V. R., R. G. Strom, V. C. Gulick, J. S. Kargel, G. Komatsu, and V. S. Kale, 1991, Ancient oceans, ice sheets and the hydrological cycle on Mars, Nature, 352, 589-594.

Belleguic, V., P.Lognonn, M.Wieczorek, 2005. Constraints on the Martian lithosphere from gravity and topography data, J. Geophys. Res., in press.

Berthelier, J. J.Grard, R., Laakso, H., Parrot, M., 2000. ARES, atmospheric relaxation and electric field sensor, the electric field experiment on NETLANDER, Planetary and Space Science, 48, 1193-1200.

Biele, J., Mimoun, D, Ulamec, S., Lognonné, P, Spohn, T., and collaborators, ML2SP assesment study, 2005. http://ganymede.ipgp.jussieu.fr/mimoun/ML2SP/ML2SP-V1.pdf

Breuer, D., and T. Spohn, 2003, Early plate tectonics versus single-plate tectonics on Mars: Evidence from magnetic field history and the crust evolution, J. Geophys. Res.-Planets, 108, E7, 5072, DOI: 10.1029/2002JE001999.

Breuer, D., D. A. Yuen, T. Spohn, and S. Zhang, 1998, Three dimensional models of Martian mantle convection with phase transitions, Geophys. Res. Lett., 25, 229-232.

Dehant, V., T. Van Hoolst, and P. Defraigne, 2000, Comparison between the nutations of the planet Mars and the nutations of the Earth, Survey Geophys., 21, 89-110.

Dehant, V., P.Lognonné and C. Sotin, Netlander: a European mission to study the planet Mars, Plan. Space. Sciences, 52, 977-985, 2004

Dreibus, G., and H. Waenke, 1985, Mars, a volatile-rich planet, Meteoritics, 20, 367-381.

Fanale, F. P., S. E. Postawko, J. B. Pollack, M. H. Carr, and R. O. Pepin, 1992, Mars: Epochal Climate Change and Volatile History, in: Mars (Kieffer H.H., Jakowsky B.M., Snyder C.W. and Matthews M.S., eds.), Univ. of Arizona Press, Tucson, 1135-1179.

Formisano, V., Atreya, S., Encrenaz, T., Ignatev, N., Giuranna, 2004. M, Detection of Methane in the Atmosphere of Mars, Science, 306, 1758-1761.

Goins, N. R., and A. R. Lazarewicz, 1979, Martian seismicity, Geophys. Res. Lett., 6, 368-370

Golombek, M.P., W.B. Banerdt, K. L. Tanaka, and D.M. Tralli, 1992, A prediction of Mars seismicity from surface faulting, Nature, 258, 979-981.

Grard, R., 1995, Solar photon interaction with the Martian surface and related electrical and chemical phenomena, Icarus, 114, 130-138.

Gulick, V. , R. M. Haberle, C. McKay, and D. Tyler, 1997. Epsodic Ocean-Induced CO2 Greenhouse on Mars: Implications for Fluvial Valley Formation, Icarus, 130, 68-86.

Harder, H., and U. Christensen, 1996, A one-plume model of martian mantle convection, Nature, 380, 507-509.

Gudkova, T.V. and V.N. Zharkov, Mars: interior structure and excitation of free oscillations, Phys. Earth and Plan. Int., 142, 122, 2004.

Hauber, E; van Gasselt, S; Ivanov, B; Werner, S; Head, J.W.; Neukum, G; Jaumann, R; Greeley, R; Mitchell, K.L.; Muller, P. and the HSRC Co-Investigator Team, 2005. Discovery of a flank caldera and very young glacial activity at Hecates Tholus, Mars, Nature, 434, 356-361.

Lognonné, P., J. Gagnepain-Beyneix, W.B. Banerdt, S.Cacho, J.F. Karczewski, M. Morand, An Ultra-Broad Band Seismometer on InterMarsnet, Planetary Space Sciences, 44, 1237-1249,1996.

Lognonné P., D. Giardini, B. Banerdt, J. Gagnepain-Beyneix, A. Mocquet, T. Spohn, J. F. Karczewski, P. Schibler, S. Cacho, T. Pike, C. Cavoit, A. Desautez, J. Pinassaud, D. Breuer, M. Campillo, P. Defraigne, V. Dehant, A. Deschamp, J. Hinderer, J.J. Lvque, J.P. Montagner, and J. Oberst, 2000, The NetLander Very Broad Band Seismometer, Planet. Space Sci., 48, 1289-1302.

Lognonné, P, Planetary seismology, 2005. Annual Review in Earth Planet. Sci., 33:19.1-19.34.

Longhi, J., E. Knittle, J. R. Holloway, and H. Wnke, 1992, The Bulk Composition, Mineralogy and Internal Structure of Mars, in: Mars (Kieffer H.H., Jakowsky B.M., Snyder C.W. and Matthews M.S., eds.), Univ. of Arizona Press, Tucson, 184-208.

Malin, M. C. and Edgett K.S., 2003, Evidence for persistent flow and aqueous sedimentation on early Mars, Science, 302, DOI: 10.1126/science.1090544, 1931-1934.

Menvielle, M.; Musmann, G.; Kuhnke, F.; Berthelier, J.-J.; Glassmeier, K.-H.; Mandea, M. H.; Motschmann, U.; Pajunpaa, K.; Pinon, J.-L.; Primdahl, F.; Szarka, L., Contribution of magnetic measurements onboard NetLander to Mars exploration, Planetary and Space Science, 48, 1231-1247.

Milkovich, S. M., and J. W. Head III (2005), North polar cap of Mars: Polar layered deposit characterization and identification of a fundamental climate signal, J. Geophys. Res., 110, E01005, doi:10.1029/2004JE002349

Mocquet, A, 1998. A search for the minimum number of stations needed for seismic networking on Mars, Plan. Space. Science., 47, 39-409, 1999.

Owen, T. 1992. The composition and early history of the atmosphere of Mars. In: Mars (Kieffer H. H., Jakosky B. M., Snyder C. W., and Matthews M. S., eds), Univ. of Arizona Press, Tucson, 818-834.

Sanloup, C., A. Jambon, and P. Gillet, 1999, A simple chondritic model of Mars, Phys. Earth Planet. Inter., 112, 43-54.

Solomon, S.S., Aharonson, O., Aurnou, J.M , Banerdt, W.B., Carr, M.H., Dombard, A. J. , Frey H. V., Golombek, M.P., Hauck II S.A., Head III, J.W., Jakosky, B. M., Johnson, C. L., McGovern, P.J., Neumann, G.A., Phillips, R. J., Smith, D.E., Zuber M.T, 2005. New Perspectives on Ancient Mars, Science, 307, 1214-1220.

Verhoeven O., Rivoldini A., Vacher P., Mocquet A., Choblet G., Menvielle M., Dehant V., Van Hoolst T., Sleewaegen J., Barriot J.-P., Lognonn P., 2005, Interior structure of terrestrial planets. I. Modelling Mars' mantle and its electromagnetic, geodetic and seismic properties., J. Geophys. Res. Planets, Vol. 110, No. E4, E04009, DOI: 10.1029/2004JE002271

Vinnick L, H.Chenet, J.Gagnepain-Beyneix and P.Lognonné, First seismic receiver functions on the Moon, Geophys. Res. Lett, 28, 3031-3034, 2001

Verhoeven O., Rivoldini A., Vacher P., Mocquet A., Choblet G., Menvielle M., Dehant V., Van Hoolst T., Sleewaegen J., Barriot J.-P., Lognonné P., 2005, Interior structure of terrestrial planets. I. Modelling Mars' mantle and its electromagnetic, geodetic and seismic properties., J. Geophys. Res. Planets, Vol. 110, No. E4, E04009, DOI: 10.1029/2004JE002271

Wieczoreck, M. A., and Zuber, M. T., 2004, Thickness of the Martian crust: Improved constraints from geoid-to-topography ratios, J. Geophys. Res., 109, E01009, DOI: 10.1029/2003JE002153.

Yoder, C.F., A.S. Konopliv, D.N. Yuan, E.M. Standish, and W.M. Folkner, 2003, Fluid core size of Mars from detection of the solar tide, Science, 300, 299-303.

Zuber, M. T., S. C. Solomon, R. J. Phillips, D. E. Smith, G. L. Tyler, O. Aharonson, G. Balmino, W. B. Banerdt, J. W. Head, C. L. Johnson, F. G. Lemoine, P. J. Mc Govern, G. A. Neumann, D. D. Rowlands, and S. Zhong, 2000, Internal structure and early thermal evolution of Mars from Mars Global Surveyor Topography and Gravity, Science, 287, 1788-1793.

Zuber, M. T., 2001, The crust and mantle of Mars, Nature, 412, 220-227.

Zurek, R. W., 1992, Comparative aspects of the climate of Mars: an introduction to the current atmosphere, in: Mars (Kieffer H. H., Jakosky B. M., Snyder C. W., and Mathews M. S., eds.), Univ. of Arizona Press, Tucson, 799-817.

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