THREE SCENARIOS FOR VALUABLE PLANETARY SCIENCE MISSIONS ON MARS: NEXT GENERATION OF CUBESATS TO SUPPORT SPACE EXPLORATION

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Planetary science originally tended to make use of "flagship" missions characterized by big satellites and expensive resources. In the near future this traditional satellite paradigm could dramatically change with the introduction of very small satellites. This shift towards smaller, less expensive devices mirrors the paradigm shift that happened in the computer industry with the miniaturization of electronics, as focus has moved from massive machines to personal computer up to smart phones.

The ultimate expression of spacecraft miniaturization is today represented by CubeSats, but while over a hundred CubeSats have been launched into Earth orbit, space-based research beyond LEO struggles to find practical application. CubeSat small size poses hard challenges for independent planetary exploration, nevertheless they remain highly attractive due to the reduced development time and cost coming from platform modularity and standardization, availability of COTS parts, reduced launch cost.

Constellations of CubeSats, collaborative networks, fractionated or federated systems are becoming popular concepts as they can offer spatially distributed measurements and the opportunity to be used as disposable sensors with a flexibility not achievable by single-satellite platforms.

We have worked towards advancing the state of the art in CubeSat missions design and implementation by defining the range of science capabilities for CubeSats beyond LEO, and by enhancing the top technological challenges to support science objectives (e.g. propulsion, communications, radiation environment protection).

Planet Mars was chosen as target destination to the purpose of this work, by selecting a set of scientific objectives for CubeSats to serve astrobiology goals and future human exploration. Missions to accomplish orbital and atmospheric measurement, in situ analyses related to biosignatures detection and environmental characterization have been explored. The opportunity to rely on already existing space assets in the proximity of Mars, or on a "mothership" for data relay or orbit insertion, has been considered in this context.

A tradespace exploration led to the definition of three classes of mission architectures, respectively based on surface penetrators, atmosphere scouts and orbiting fleet. Each architecture has been assessed in the perspective of science return against a set of leading indicators that draw out cost, utility, complexity, technology readiness among others. For each class a mission concept has been created, providing a basis to elicit the definition of top-level requirements and to assess the value of science return in the context of complex mission scenarios.

I. INTRODUCTION

The evolution of computers can be used as an analogy for the evolution of spacecraft. The advancement and miniaturization of electronics allowed the shift from mainframes to personal computers up to smartphones, and exponentially increased the number of people that could afford this technology. Similarly, in the last decade lower-cost and smaller-size satellites have substituted large spacecraft architectures that originally tended to be monolithic, and the number of organizations that gained access to space has been expanded. Small satellites became important in providing cost-affordable access to space to developing countries where space industry was not yet consolidated [1]. NASA's New Frontiers and Discovery programs are two examples of how larger "Flagship" planetary science explorations are being complemented by many smaller and more frequent missions using fewer resources and shorter development times. The use of new technology and broaden university and industry participation in NASA missions are additional key factors enabling this paradigm shift. In academic field, universities have developed small satellites as a great tool to give hands-on experience to students. The ultimate example of this diversification enabled by technology miniaturization is being represented by the proliferation of micro- and nanosatellites, in particular by the expansion of CubeSats.

In 1999 the CubeSat standard was defined within the CubeSat Project, a collaborative effort between Prof Jordi Puig-Suari at California Polytechnic State University and Prof Bob Twiggs at Stanford University [2]. The standard specified that a 1 Unit CubeSat shall measure 10x10x10 cm and shall have a mass of maximum 1 Kg (later increased up to 1.33 Kg on August 2009 [3]). A 3-unit standard has also been defined; cubes can also be stacked together to create larger volumes with standard configurations up to six and even twelve units. The implementation of a common standard for a low-cost, fast-developed access to space gave a new approach to space system design, mainly in the academic field, where new CubeSats programs have been created. Only four years after the definition, in 2003 six CubeSats were launched opening the CubeSats era.

Current CubeSat and nanosatellite missions are mostly developed for LEO (Low Earth Orbit) application, and the number of scientific goals/tasks that they can perform is still limited. CubeSats are nowadays a mature technology to perform Earth observations, and they are a valid educational tool to train young engineers and students in the process of conceiving, implementing and operating a space mission. CubeSats are also frequently developed in academia and by space agencies as way to build spacecraft in a quick and affordable way [4] [5]. For example, NASA Jet Propulsion Laboratory has recently developed M-Cubed/COVE in cooperation with University of Michigan [6]. COVE will validate an image processing algorithm designed to survey the impacts of aerosols and clouds on global climate change. NASA JPL is also designing LMRSat [7] (Low Mass Radio Science Transponder Satellite, 2U). NASA Goddard is currently developing HeDi (Helium Doppler Imager, 3U CubeSat) and TechCube 1 (technological demonstrator, 3U) [8]. In academia, MIT and Draper Lab are building ExoplanetSat [9], a 3U CubeSat that aims to detect superEarth exoplanets by the transit detection method. Another CubeSat being designed and tested at MIT is MicroMAS [10], which aims to use a spinning payload to study Earth's atmosphere. Other CubeSat missions for LEO have been recently developed at University of Michigan [11] (Radio Aurora Explorer, RAX), University of Colorado [12] (Colorado Student Space Weather Experiment, CSSWE), University of Hawaii [13] (UNP 6, Radar Calibration CubeSat), and others. In Europe many universities have developed and are currently running CubeSat projects. In the last few years, the European Space Agency has carried out an important initiative that ended with the launch of 7 CubeSats from selected universities of the member States in February 2012 thanks to the new VEGA European Launch Vehicle [14]. Other universities in Europe have already launched their own satellites on commercial launchers, while other are ready to launch in the next few months. Most of the CubeSat today in orbit have primarily educational objectives and secondarily technological demonstration and/or scientific purposes [15]. After the successful first initiative, ESA is now promoting new CubeSat projects both in the education and in the scientific missions areas. Two other programs currently under development are worth mentioning, both aimed at setting a constellation of CubeSats in LEO. QB50 is a FP7 international project coordinated by Von Karman Institute for Fluid Dynamics. Aim of the scientific mission is to study temporal and spatial variations of a number of key parameters in lower thermosphere (90-320 km) with a network of about 40 double CubeSats [16]. HumSat is an international project initiated by the University of Vigo, under the patronage of ESA and UNOOSA, with the objectives of monitoring climate changes and supporting humanitarian initiatives. The aim of the mission is to launch a CubeSat constellation for supporting a general-purpose communication space-based service, above which the different users will be expected to build and use their own application [17] [18] [19].

The possibility to deploy multiple satellites in the same launch, the increased availability of launches (as piggy-back payload) and the advent into the market of private launchers providers, the interest from industries and military organizations in the development of CubeSats as fast-response technology demonstrators, and finally the support of space agencies over the development and launch (e.g. ESA-Education Office's 2008 CubeSats on VEGA Maiden Flight project, 2013 Fly Your Satellite! program and NASA ELaNa program, which first call for proposals was in 2010) led to a total of 175 CubeSats launched into Earth orbit in the decade 2003-2013 [20]. Even if most of them have educational objectives, the latest trend is to move gradually from pure educational purpose to technological and scientific objectives. Indeed, a relevant number have also been developed for technology demonstration, while Earth observation and scientific purposes are also envisaged as mission objectives of some of them.

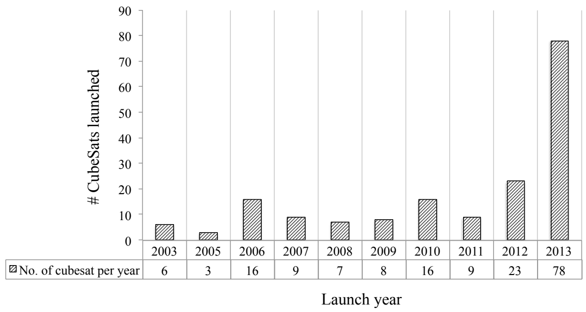

Fig. 1: Number of CubeSat launched per year in the decade 2003-2013. Source: [20]

Moreover, CubeSats missions beyond Low Earth Orbit are being studied. Actually, one CubeSat for technology demonstration for future missions to the Moon has already been launched [22]. Furthermore, CubeSat community members are also starting to propose the use of this class of small satellites for interplanetary missions. A series of yearly workshops and conferences [22] hosted for the first time at Massachusetts Institute of Technology (MIT) in 2012, focusing on interplanetary small satellites and CubeSats missions, draw the attention on the number of challenges that designers will have to overcome: longer lifetimes, propulsion for trajectory changes and potentially entering orbit, power, communications from vastly further distances than Earth orbit, higher radiation outside Earth's protective magnetosphere, and instruments to make meaningful measurements.

The continuing improvements of the abovementioned technologies could enable a much broader set of missions than before thought possible, with CubeSats remaining highly attractive due to the reduced development time and cost coming from platform modularity and standardization, availability of COTS parts, reduced launch cost. A study [23] of the NASA Innovative advanced Concepts (NIAC) showed that spacecraft and payloads useful for Solar System exploration, astrophysics, space physics, and heliophysics can utilize a new Interplanetary CubeSat architecture, enabling lower-cost, up-close measurement of distant destinations, including Mars, asteroids, comets and the Moon.

A key driver for succeeding seems to reside in the employment of these platforms in configuration of multiple distributed spacecraft. Constellations, collaborative networks, fractionated and federated systems are becoming popular between the developers, these concepts being able to demonstrate spatially distributed, simultaneous and shared measurements, among other emergent capabilities of distributed satellites working in concert as a "system of systems" and the opportunity to be used as disposable sensors with reliability and flexibility not achievable by monolithic single-spacecraft platforms. Distributed small satellites could produce more precise data than a single highly capable large spacecraft, and could open avenues of data collection unattainable by a monolithic mission profile. Fleet of nanosatellites or CubeSats are likely to play a role in future planetary missions, but most presumably as daughter craft carried to their destination by larger spacecraft.

The authors explored the state of the art in CubeSat missions design and implementation by defining the range of science capabilities for CubeSats beyond LEO, and by enhancing the top technological challenges to support science objectives (e.g. propulsion, communications, radiation environment protection). This paper highlights the emerging capabilities of distributed small-satellites in the context of a planetary science mission in the Solar System, addressing the high-level objectives defined by formal processes within the scientific community. Planet Mars was chosen as target destination to the purpose of this work, by selecting a set of scientific objectives for CubeSats to serve astrobiology goals in preparation for future human exploration.

NASA-MEPAG (Mars Exploration Program Analysis Group) living documents [24] provided the authors the opportunity to explore the key activities necessary to fill the gap of knowledge in a particular area of interest. High-level scientific objectives achievable by distributed platforms have been prioritized, by enhancing measurement and interaction capabilities that are not attainable with single-monolithic structures. The purpose was to generate and explore space mission concepts aimed at gathering unprecedented measurements and data about the planet Mars' ecosystem enabling in turn the future human exploration. Preference was given to unconventional architectures of distributed space assets, networks of small and replicable satellites, low-cost platforms. Three mission concepts have been generated, based on the deployment of a large number of small spacecraft in orbit or on a global distribution of a planet's surface and subsurface landers and scouts.

Distributed satellite systems are often overlooked in the preliminary comprehensive science mission proposals, either because their value proposition fails in justifying the risk or expense, or because decision-making is biased by the heritage of traditional monolithic architectures. The needs of alternative solutions are hence not explicitly stated and remain unrevealed throughout the process of concept development and preliminary design. The investigation described in the following sections section consists in searching for evidence of these needs and bringing to light emerging capabilities, issues, risks of distributed small-satellite solutions through the concept exploration of a planetary science mission to Mars.

Destination: Mars

Mars has a unique place in solar system exploration: it holds keys to many compelling planetary science questions, and it is accessible enough to allow rapid, systematic exploration to address and answer these questions. The program of Mars exploration over the past 15 years has provided a framework for hypotheses to be formulated and tested and new discoveries to be pursued rapidly and effectively with follow-up observations [25]. According to the Decadal Survey for Planetary Science 2013-2022, the study of Mars as an integrated system will continue well beyond the coming decade, following the approach that produced missions supporting one another both scientifically and through infrastructure, with orbital reconnaissance and site selection, data relay, and critical event coverage. The challenging science objectives will focus on understanding the evolution of the planet as a system, focusing on the interplay between the tectonic and climatic cycles and the implications for habitability and life. Future missions will implement geophysical and atmospheric networks, providing in situ studies of diverse sites, and bringing to Earth additional sample returns, addressing in detail the questions of habitability and the potential origin and evolution of life on Mars.

Over the past decade the Mars science community, as represented by the NASA Mars Exploration Program Analysis Group (MEPAG) has worked to establish consensus priorities for the future scientific exploration of Mars, formulating three major science themes that pertain to understanding Mars as a planetary system: 1) understand the potential for life elsewhere in the universe; 2) characterize the present and past climate and climate processes; and 3) understand the geologic processes affecting Mars's interior, crust, and surface. A fourth theme, the MEPAG Goal IV, identifies the investigations that are still needed to prepare for human exploration. From these themes, MEPAG has derived the key science questions that drive future Mars exploration, providing the science community with updates on the answers found, and shaping future directions [26].

The Goal IV is different in nature from the former three, commonly referred to as Life, Climate, and Geology. Unlike Goals I-III, which focus on answering scientific questions to develop a comprehensive understanding of Mars as a system, Goal IV addresses issues that have relatively specific metrics related to increasing safety, decreasing risk and cost, and increasing the performance of the first crewed mission to the planet [27].

Precursor activities and technology demonstrations in several venues (Earth, LEO, International Space Station, and nearby celestial objects such as the Moon or asteroids) would be involved in the long-term preparation for the human exploration of Mars. Although all represent an important and necessary part of the forward path, the connectivity between these precursor activities and the technology demonstration roadmap are maintained separately and considered complementary to the required science data cited in the MEPAG Goal IV document. For these reasons the precursor activities listed in the document result to be to a lower extent constrained by the necessity of low-term engineering and cost feasibility demonstrations. They are rather explicitly tied to those data products the scientific community requires to fill the gaps of knowledge on critical features of the planet's environment, before planning ahead a manned mission to Mars.

II. SCIENCE GOAL ANALYSIS

The aim of this work is to generate some space mission concepts where CubeSats play a role in supporting exploration for valuable planetary science beyond LEO. The root problem to be addressed in the formulation of a mission concept was to learn about planet Mars in connection to human exploration. As inferred from MEPAG documents review, in order to prepare the human exploration of Mars, it is necessary to fill the gap in the knowledge in and to address the uncertainties related to specific phenomena in the Mars' environment (orbit, atmosphere, ground). This is especially true on regional/global scale.

Choosing a key activity (observation, measurement, sounding, and others) that fills the gap of knowledge in a specific area of interest (ground bio-hazard, atmosphere composition, presence of dust and/or micrometeoroids in orbit) let us "build" low-cost/fast-delivery science mission concepts.

Principal stakeholders of this study have been identified within the scientific community. We envisage that space mission planners, strategists, and designers who are/will be building the future human missions to Mars would benefit from mission results. The top-level scenario calls for significant objectives: innovative, unprecedented and visionary concepts have been explored, such as mission architectures based upon constellations, swarms, distributed satellites, single-instrument multiple-units platforms; technology return for Earth-related applications was taken into account, as the prospect to inspire the general public imagination.

The problem statement reads as follows: to establish a low-cost/fast-delivery space asset at Mars for filling the lack of knowledge on specific phenomena in the Martian orbit, atmosphere and on ground on regional/global scale, that may affect the future human exploration of the planet. To provide the scientific community with unprecedented measurements and data that reduces the level of uncertainty to support the long-term vision of human exploration of Mars.

Selection of Activities

The science goals analysis started with the identification of the Strategic Knowledge Gaps (SKG) and with the mapping to the different activities needed. See Table 3 for an extract of the list of activities and SKG prioritized by the Precursor Strategy Analysis Group (P-SAG). The comprehensive P-SAG report and associated science traceability matrix, including technology demonstrations and investigations not needing Mars flight opportunities can be found in [28].

We analysed how these activities are mapped to the various investigations, also called high-level science goals, and how investigations in turn could be driven by single-or-multiple activities, or measurements. Priorities among the multiple investigations were determined by the P-SAG first assessing the impact of relevant data within each investigation, and then assessing the value of new precursor data against timing criteria. The result is a classification based on a dual ranking: “timing” and “priority”. The first metric indicates which activities are needed earliest, the second is a metric to recognize if a set of activities enables critical need or mitigates high-risk items. The total combined priority indicates that measurements needed earliest were prioritized ahead of measurements of equal priority needed later. Priority and timing levels have been defined as per Table 1 and Table 2. The ranking defined by MEPAG and P-SAG allowed the authors to recognize which activities are being considered critical and what are the needs to be met before others. A selection of activities has been made on a basis of location and typology. Were then discarded those planned activities in Earth orbit or in the vicinity of Phobos/Deimos in preparation for a Mission to Mars, activities that would provide for sample return or demonstration of technologies for rendezvous and docking, entry, descent and landing, ascent, forward contamination, among others. The selection enabled to reduce from 78 to 30 the number of GFAs subject to further investigation.

Attention has been given also to the need of distribution of data products (global coverage, full diurnal cycle, etc.) and to the “class of interaction” between spacecraft and mission subject. The latter refers to a classification made according to two variables, the location of the mission subject (e.g. ground, atmosphere, orbit) and type of sensing (e.g. measurement, observation, in-situ analysis, etc.) Six classes have been identified: A. upward remote sounding of atmosphere; B. downward remote sounding of atmosphere; C. remote sounding of surface; D. in-situ surface measurements; E. in-situ orbit measurements; F. in-situ atmosphere measurements. The resulting distribution of GFAs between classes is shown in Figure 2: remote-sounding classes (i.e. A, B, C) almost equally share the half of the total number of activities, while the three remaining classes include in-situ measurements most needed on the planet surface.

Timing	Description
IV	Needed to plan human missions to Mars orbit
IV Early	Needed to plan architecture of the first human missions to the Martian surface
IV Late	Needed to design hardware for first human missions to the Martian surface
IV+	Needed for sustained human presence on the Martian surface

Table 1: Shorthand for human mission goals timing [27-28]

Priority	Description
High	Recognized as an enabling critical need or mitigates high risk items (items can include crew or architectural performance)
Medium	Less definitive need or mitigates moderate risk items
Low	Need uncertain or mitigates lower risk items

Table 2: Criteria for setting priorities used by P-SAG [27-28]

SKG		Gap-filling activity	Priority	Timing
A1. Atmosphere	Upper	A1-1. Global temperature field	High	IV-
		A1-2. Global aerosol profiles and properties	High	IV-
		A1-3. Global winds and wind profiles	Medium	IV-
A3. Particulates	Orbital	A3-1. Orbital particulate environment	Medium	IV-
…		…	…	…
D1. Resources	Water	D1-3. Hydrated mineral compositions	High	IV+
		D1-4. Hydrated mineral occurrences	High	IV+
		D1-5. Shallow water ice composition and properties	Medium	IV+
		D1-6. Shallow water ice occurrences	Medium	IV+

Table 3: Partial listing of P-SAG Strategic Knowledge Gaps and Gap-filling Activities with priority and timing [27-28].

This result tells that on one hand the remote-sounding activities are as important as the direct in-situ measurements, and indeed being these tasks preliminary and preparatory for a manned mission to the planet, the soil and the subsurface gain most of the interest from scientific community and mission planners. The push towards this interest is also given by the recent success of robotic landers and rovers' missions, which, however, have allowed so far getting a good knowledge of the planet only at the local level in some selected spots.

In contrast, the analysis made on the MEPAG and P-SAG documentation already cited, highlights the need of measurements globally distributed in time and space, that robotic missions mentioned above could not offer. The proof is the fact that despite the "class D" necessary activities (in-situ surface measurements) represent 40% of the total, only two of them has been evaluated with a combined score of high priority and timing, while the remaining ones got a medium/low average ranking, their impact on the mitigation of risk being considered moderate and/or the necessity of results in this area not compelling.

In order to adequately consider the full range of possible designs, and avoid a priori design selections without analysis or consideration of other options, three activities have been selected within the top-ten list illustrated in Table 4: A1-2 Observation of global aerosol composition, B2-1 Detection of biohazards, A3-1 Observation of orbital particulate in high Mars orbit. The choice has been made by selecting activities that were representative of different classes of interaction, different ranking position (combination of priority and timing), and manifested necessity of spatial and temporal data distribution. This approach allowed regarding for the preferences of key decision makers since the early stages of design, still leaving the concept generation open to different options and creative enough to envision in which ways it could be possible to explore planet Mars in the future. For each of the activities identified a mission concept has been generated. The three scenarios are described in the following sections.

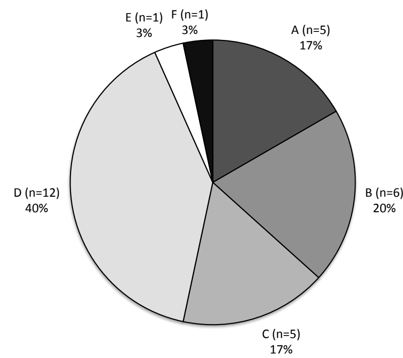

Fig. 2: Distribution of Gap-Filling Activities within classes of interaction. Classes A,B,C = remote-sounding, D,E,F = in-situ measurements. See text for in-depth analysis and details.

GFA	Description	Data distribution needs	COI	Rank
A1-1	Observation of global temperature field	Full diurnal coverage	B	1
A1-2	Observation of global aerosol composition	Global coverage, all local times	B	1
B1-2a	Measurement of global surface pressure	Full diurnal cycle, multiple locations	D	2
B1-2b	Observation of local/regional weather	Full diurnal cycle coverage	A	2
B2-1	Detection of biohazards	Multiple environments	D	2
A1-3	Observation of global wind velocity and direction	Global coverage, global distribution	B	3
A3-1	Observation of orbital particulate in high Mars orbit	Equatorial plane, multiple altitudes	E	3
B1-1	Dust and aerosol activity climatology	n/d	B	3
B1-2c	Observation of local weather at multiple sites	Multiple locations, full diurnal cycle	A	3
B5-1	Measurements for presence of ground ice	n/d	C	3

Table 4: Top ten Gap-Filling Activities as ranked by MEPAG and P-SAG [27-28]. COI = "class of interaction" as defined throughout the analysis. Rank refers to the total priority given by the combination of "timing" and "priority" values. Same rank values refer to equal timing and priority scores. Data distribution needs are deduced from GFAs statements and descriptions as per [27]. n/d = not defined. See text for further details.

CONCEPT A: ORBITAL PARTICULATE

The source of orbital particulate in high Mars orbit is represented by micrometeoroids and dust rings. Micrometeoroids are fragments of bigger space corps as asteroids or comets, with dimensions ranging millimeters to meter. Because of their high velocity, these corps could jeopardize spacecraft and endanger the success of a mission. Origin, composition and main characteristics of these corps shall be understood performing numerous observations. This could be achieved by gathering enough data to create a consistent statistic model. The easiest method is to observe the burning trail they left after being entered in Martian atmosphere and gathering information about mass, dimensions, composition and velocity based on a spectrometric analysis.

Regarding dust rings, their existence is still to be proved [29,30]. Their orbit should be located in the equatorial plane of Mars [31] between Phobos and Deimos. They would be able to induce optical and communication instruments malfunction, and the particles might have a non-uniform distribution. Thus an adequate number of satellites seem to be mandatory to have a sufficient probability to get enough close to discover those particles clouds. A sufficient proximity would be required to surely identify those particles, as their diameter would range under the millimeter. As a result, an impact sensor would be a good solution to detect dust particles.

A mission of CubeSats as distributed systems with the purpose of detecting this particulate has both scientific and engineering implications: studying micrometeoroids and dust rings origins and composition will improve the knowledge of the Solar System environment and, at the same time, discovering the position of Mars dust rings and building up a statistical map of the distribution of micrometeoroids could avoid the failure of future mission in Mars environment.

Two scientific goals derived from the above statements: 1) To investigate the statistic distribution through the Martian year of Martian micrometeoroids' mass, velocity and composition using meteor trails spectroscopy in order to understand the origins of Martian micrometeoroids and for human exploration hazard mitigation; 2) To search for Martian dust rings and determine the spatial and particle size distributions, composition, origin, density and their time evolution in order to understand Martian system history and evolution and for human exploration hazard mitigation.

Micrometeoroids

The authors focused on the coverage needed in order to get enough data to create a statistical distribution and predict the number of events in specific areas. The optical cameras inside a CubeSat are not likely to have enough resolution to define objects with 1 mm radius. The best option is to look for trails produced by the ablation of micrometeoroids in the atmosphere. The first analysis on [32], combined with a simulation of a ballistic orbit, determined the lower limit of the range for the length of micrometeoroids trails. A constellation of nanosatellites in circular orbits around Mars at an altitude that allows optical observations of impact events has been designed.

Two figures of merit have been considered and analysed: Resolution and Coverage. These figures of merit have been influential in the same way since in order to reach our goal it is necessary a wide coverage so that the highest number of events possible can be detected. At the same time, it is very important to have a very good chance that dedicated devices (camera and spectrometer) are allowed to see in a satisfactory way what is really happening where they are pointing to, so that the image can be properly analysed and processed in order to obtain the required information.

Therefore, in order to have a better confidence identifying micrometeoroids, satellites should be positioned in as low as possible orbits; nevertheless, having low altitudes lead to the impossibility to fulfil the coverage requirement.

Preliminary calculations about camera resolution allowed by current technology resulted in a operational altitude of only 20 km. Latitude range between 40° north to 40° South has been chosen after trade-off studies about surface analysed, landing sites for human exploration and mission costs. This represents about 65% of global surface; increasing the maximum latitude observed will increase this percentage but ΔV limitations have to be taken into account. The opportunity to rely on already existing space assets in the proximity of Mars, or on a mothership for orbit insertion in the equatorial plane has been considered in this context.

A second iteration of design allowed to consider better camera devices but also fixed the maximum inclination achievable: a constellation of 30 satellites with FOV of 30° each, altitude 2000 km, 10 orbit planes with inclination ranging from -40° to 40° has been assessed. Two main problems arose with this configuration: The instant coverage with this configuration was good, but the resolution of each pixel was near to the limit imposed to define a trail. The ΔV needed to increase inclination from equatorial plane to the maximum inclination (Δi=40°) was 2.61 Km/s, too expensive even divided among on-board propulsion system and the mothership. Upper limit for ΔV provided by a CubeSat propulsion system is currently around 1 km/s, that establishes and upper limit of Δi to 15° for plane change.

A much lower altitude (e.g. 500 km) would have led to a very low instant coverage about 10%. The option of giving to the camera an elevation angle between body axis and the pointing vector was taken into account. A good compromise has been found setting altitudes at 1000km, with a starting inclination of 10°. Combining this with a second manoeuvre provided by the satellites' propulsion system the maximum inclination has been fixed to 25°.

To obtain monitoring of upper and lower latitude some of the satellites at 25° of inclination would have cameras pointing latitudes that ranges between 25° to 40°.

Simulation with AGI-STK with a Coverage Definition tool showed an instant mean coverage value of 22.05%, 90% coverage of the planet after 1:30 h, 98% after 3:00 h.

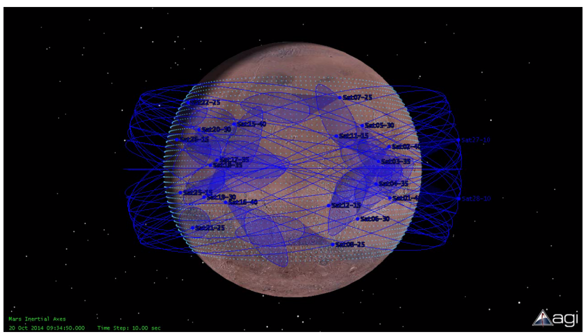

Fig.3: Simulation sample after 6 months of operations

Mission Scenario

A possible mission scenario encompasses three different phases. The first phase will be divided in: arriving in the Martian environment relying on a the mothership; to maneuver in order to reach the already chosen orbit; to perform all the operations needed for the satellites to be fully functional and ready to operate. The last phase could take months, depending on the kind of propulsion system chosen.

The second phase will focus mostly on the measurements: dust images taken of the micrometeoroids trails. This will implicate a precise attitude control, especially during the camera pointing. During the second phase the system will communicate with the chosen network to send data and images to the ground segment, where they will be processed. Image processing could also be achieved on board. In the first case, the satellites would have to store every single image and transmit data very frequently. With an on-board processing system, images without trails and false positives would be discarded and there would be more available memory for data storage and less data to be transmitted. On the other hand this affects the system complexity.

The third and last phase will be the disposal operation, which would implicate a maneuver for the end of life of the operations, if sufficient fuel still available. The disposal could be obtained by crashing on Mars' surface. To fulfill the mission requirements one possible configuration of a single satellite could be a 3U CubeSat, 1U for the camera, 1U with propulsion system and spectrometer analyzer, 1U for avionics. Spectrometer can analyze the optical data gathered by the camera to process data about composition of micrometeoroids observed

Dust rings

This section will focus on a possible mission architecture that seeks for dust rings' existence and investigates their characteristics. Several studies state that is more likely that dust ring resulted from impact on Phobos and Deimos. The search will be concentrated specifically on the zone from Mars' atmosphere to Deimos, approximately 23500 km far from the planet, and for the most part on a region between the two Martian moons.

A CubeSat mission can accomplish the task by means of impact with the dust or by capturing an image of it. The measurements would require some post processing work; spatial and temporal distribution of dust will be the result of a post processing over the data gathered during the mission, which shall last for one Martian year at minimum in order to gather a number of impacts statistically relevant. Therefore the total space swap by a hypothetical constellation has been considered as figure of merit for the analysis.

Orbit analysis

Decaying orbits with continuous propulsion systems were discarded for cost and size reasons. Polar or equatorial circular orbits were also considered: circular orbits imply a fixed altitude from the planet, so the regions that would be studied are small, and limit the probability of dust impacts; polar orbits are demanding in terms of expensive maneuvers for inclination change. Elliptic orbit was the third option evaluated, allowing the constellation to sweep more space with respect to the previous options. A simulation performed with a Simplified Perturbation Propagator (SPG4) revealed that an equatorial orbit with approximately 6000 km perigee and 23000 km apogee would change the ascending node argument of almost 0.5 degrees per sol, being back in on initial position in one Martian year; in this case a multiple-satellite system would sweep most of the Martian environment of interest during its mission lifetime.

Mission Scenario

The first part of the rings mission would involve the Earth-Mars transfer and the orbit insertion by means of a mothership from an equatorial circular orbit of about 30000 km radius. In a second step a Hohmann transfer would place the system inside the zone of interest, where the mothership would operate the deployment of the first satellites.

Six satellites deployed with a 60° phasing distance would need to operate themselves an impulse to lower the perigee. The mothership could then perform a maneuver to move to a lower circular orbit (with a radius matching the value needed by the micrometeoroids mission described above) deploying the other set of satellites.

The measurements the satellites would take rather need post-processing on ground, this meaning that one critical aspect of the mission is to communicate back to Earth where those will be analyzed. Disposal operations have been considered in preliminary analysis: disposal can be obtained by escaping Mars' influence sphere with an escaping maneuver, by crashing on one of the Martian moons or by crashing on Mars.

Payload and communication strategies

The measurements needed would require the implementation of an impact sensor, of a dust analyzing system able to detect charged particles after dust impact, and of an optical sensor (camera) for the imaging capture of in-orbit dust.

As the impact sensor is concerned, the implementation would require the development of a passive type piezoelectric sensor with a large frontal area to enhance dust impact probability and the development of an opening system and a structure to support the sensor itself. A quick and simple solution for dust impact sensors' implementation is to use a passive sensor on big surface with electric properties. This type of sensor allows to optimize the available power on board and to increase the impact rate. Piezoelectric polymers materials can be used to detect the deformation of the impact surface.

As the dust analysis system is concerned, the implementation would require the arrangement of a large metal alloy impact surface, a sensors system able to detect charged particles (ions and electrons), and the activation of an electric field between impact surface and sensors system, in order to separate ions and electrons. The dust analyzer would measure the electric charge carried by dust particles, the impact direction, the impact speed, mass and chemical composition.

As far as the camera is concerned, this would require the implementation of an optical system that enhances visibility of micrometric dust size in a kilometric range and the development of an attitude control system with an orbital database for optimization of lighting conditions that will help in the visualization.

Given these options, three solutions have been proposed with the aim to be evaluated in a later step of design: dust detector supported by a camera, inflated sail, deployed sail supported by multiple satellites. A drawing concept can be seen in Figure 4.

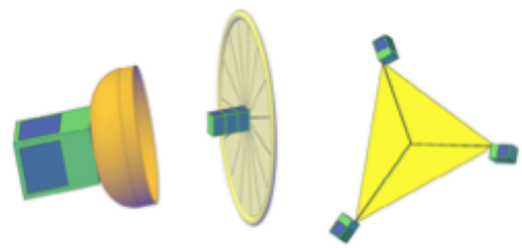

Fig. 4: Dust detector, inflated sail , deployed sail supported by satellites

For the transmission of the mission data, telemetry and the parameters for satellites attitude control a network able to connect the in-orbit systems and the ground stations shall be used. Two main parts of this network have been considered in combination the Deep Space Network (DSN) and a Satellite Relay System (SRS). The DSN must be able to establish a communication link between Mars and the Earth: this means that this system must be equipped with a high gain antenna with a high pointing precision and a source unit powerful enough. This segment can be supported by a pre-existent orbiter of a precedent mission, or by the mothership. We can consider a relay satellite orbiting on a circular trajectory of 24000 km radius that connect to the satellites when they run on their orbit's apogee. This architecture represents is expensive because of the implementation of an appropriate relay satellite, but is also appropriate because no need of pointing accuracy, high gain antennas or high power signals to establish a link are envisioned for the CubeSats.

Another solution could be considering a ground station on Mars surface as a relay system. This ground station will transfer data to an NASA/ESA orbiter on Mars low orbit that then links to DSN. This strategy however would need an additional link to be implemented. More detailed analyses and trade-offs have to be performed in terms of architecture cost, data volume to transfer, availability of the link, and architecture reliability.

CONCEPT B: AEROSOL COMPOSITION

This section concerns the generation of a mission concept for the study of the Martian atmosphere, in particular the aerosol composition, by means of a system of distributed nanosatellites. The mission's aim is to provide the scientific community, mission designers and other interested users with relevant data capable of improving the knowledge of the Martian atmospheric sciences, with an eye towards future human habitation, through deployment of low-cost, fast deliverable and multi-purpose platforms.

The scientific goal for this mission concept states: "To characterize and study atmospheric features and processes of Martian atmosphere and to investigate their interaction with future human in situ missions". The broad scope is to understand how the Martian atmosphere affects possible human operations on Mars, with an eye towards future human habitation. This involves the collection of data that help in assessing the feasibility of Martian human exploration and the possibility to support it. The knowledge of atmospheric processes and the interaction between human operations (both crews and equipment) and the atmosphere itself have been considered fundamental, and so included in the scientific goal. The GFA identified requires global measurements of the vertical profile of aerosols (dust and water ice) at all local times between the surface and >60 km These observations should include the optical properties, particle sizes and number densities.

Preliminary mission architectures definition

A preliminary draft of the mission concept was developed through the identification of different types of architectures, including, since the beginning, either orbiters and landers with the employment of possible balloons, that could operate in orbit and directly on ground, in order to have a more complete and accurate coverage using both points of view.

Two main different distributions for those two types of devices have been envisaged: 1) a fleet of few orbiters, and several little landers with the instrumentation that cannot be contained on board the orbiters; 2) a fleet of several little orbiters that keep each lander connected with the others, and a few important landers with almost the full set of payloads.

The configuration which could be able to provide a relatively low cost mission has been taken into account, in order to accomplish one of the mission drivers previously defined: low cost, ease of deliverability, use of multipurpose in situ platforms. Another key point since established since the very beginning has been the possibility to establish a strong data link between on-mars and on-orbit stations. Preliminary trade-offs were performed over the number of satellites within the orbiter fleet, the type of landers within a fleet and the choice of landing sites. As an example, three options have been considered since the beginning for the type of satellites: 1) a ground platform for lower atmosphere measurements with a balloon connected and a retractable wire for measurements in higher altitudes; 2) a ground station without balloons but with the prerogative of a possible re-use by future astronauts. This lander would detect information about the upper atmosphere during its landing; 3) a fleet of landers detecting information about the upper atmosphere during re-entry, landers able to extract a balloon during landing to spend more time in atmosphere and working, once landed, as a classical lander able to provide information.

Concepts of operations

As a set of 6 Concepts of Operations (ConOps) was evaluated, in particular speculations have been made on the space segment and on systems able to land on the surface of Mars (hereinafter called Mars segment). It was clear since the choice of high priority scientific objectives, and right from the preliminary mission concept elaborated that both space segment and Mars segment were essential and needed for the success of the mission, given the current state-of-the-art for sensors taken into consideration. The choice of command, control and communications architecture has been made in parallel with a trade-off work based on the assumption that Space segment and Mars segment are similar in all the ConOps evaluated. The conclusion from the communication system study led to an architecture in which every CubeSat (belonging to both space segment and Mars segment) shall be able to perform communications with orbiters capable of direct Earth communication, such as a mothership, Mars Reconnaissance Orbiter (MRO), Mars Odissey, Mars Express or other future data relay satellites.

Other common features between ConOps evaluated are: 1) all the landers are left by the mothership in an orbit that allows landing in at least two identified landing areas, lately chosen to be Elysium Planitia and Utopia Planitia. 2) All the orbiters are left by a mothership in circular, low-altitude Martian orbits. This is to ensure an effective communications architecture: low altitude orbits allows avoiding powerful transmitters and big receivers, circular orbit allows the signal strength to be uniform along the orbit. The availability of data relay satellites may be low, due to sharing with other missions, so orbiters shall provide a link between Mars segment and the three orbiters mentioned above in case they are not in line of sight.

ConOps	Description
Tethered Balloons	Space segment: several CubeSats, capable of atmospheric entry, performing remote sensing of the upper atmosphere. Mars segment: CubeSats of the space segment used as landers. During the atmospheric entry and descent, CubeSats gather data regarding the upper atmosphere (that cannot be collected by the space segment). After the landing on Mars, CubeSats are able to gather atmospheric data in a 0–30 m altitude range.
Free-flying Balloons	Space and Mars segment: same as tethered. During the descent phase, each CubeSat deploys a free-flying balloon, which is inflated with Martian air. After the balloon is deployed atmospheric data is gathered. After a few days of data collection, the balloon lands and gathers atmospheric data from the surface.
Landers shower	Space segment: several CubeSats, capable of atmospheric entry, that performs remote sensing of the upper atmosphere. Mars segment: CubeSats used as landers. The same CubeSats performing remote sensing are able to perform atmospheric entry and descent, while they gather atmospheric data, when atmospheric entry aerodynamics allows it. Once they have landed, they gather atmospheric data from the surface of Mars. No disposal of the space segment is required.
Ballistic	Space and Mars segment: same as Landers shower. Atmospheric data is gathered during the descent, until the touchdown on Martian soil.
Sounding rockets	Space segment: several CubeSats that perform remote sensing of the upper atmosphere. Mars segment: several CubeSats able to land on the surface of Mars, each one carrying a sounding rocket. During the atmospheric entry and descent, these CubeSats do not gather data regarding the upper atmosphere. After landing on the Martian surface, each lander is able to deploy and operate its sounding rocket that is used to gather atmospheric data from Martian soil to suborbital altitudes, where no data can be collected from the space segment.
Rockoons	Space segment: several CubeSats that perform remote sensing of the upper atmosphere. Mars segment: several CubeSats able to land on the surface of Mars, each one carrying a rockoon (a sounding rocket whose ascent is assisted by a balloon).

Table 5: descriptions of the six Concept of Operations

To evaluate the best ConOps, several figures of merit were used, grouped in three families: objectives accomplishment, objectives balance and ConOps features. The first family describes how well and completely high priority scientific objectives are met; the second family describes, among the accomplished scientific objectives, if gathered data is more useful to human Martian exploration or Martian atmospheric sciences; the third describes the general features of a given ConOps.

Mission concept definition

Starting from the preliminary configuration chosen and tradeoff carried out on the basis of the FoM identified including orbiters and landers, the final mission concept evolved as follows:

The orbiters fleet: the space segment goes from 3-6 to 12 orbiters of 3U dimensions, 4 orbital planes with 3 orbiters on each, in order to have a more complete coverage of Martian surface, as demonstrated thanks to STK simulations, and to perform remote sensing of the upper atmosphere. The choice of using 12 orbiters comes from the fact that for each orbital plane, there are 3 online orbiters to guarantee the accomplishment of the mission in case of any failure.

The choice of using orbiters of 3U dimensions was evaluated as a good dimension for on-board payloads and cameras.

The Mars segment includes two kinds of spacecraft: 2 landers, one for each landing site, with a tethered ballon (as described in ConOps 1, and smaller CubeSats as described in ConOps 4). Landers are stored in a CubeSat with a 3U configuration, not including balloons support system (e.g. helium canister), from which one balloon would be inflated and deployed with retractable wire.

The lander swarm is composed by at least 20 CubeSats in 1U configuration, which dimensions have been imposed downstream of a definition of necessary payloads to make measurements. These CubeSats, smaller and considered more resistant to impact, are released in sets of 5 units from the mothership during the “re-entry” phase, passing through the Mars atmosphere until speeds and thermal flows became sustainable for satellites structures. Further analyses needs to be performed regarding the combination of satellites during atmospheric entry.

For the final mission concept, two landing sites were chosen: Elysium Planitia and Utopia Planitia, respectively in equatorial and polar planes, enough far in latitudes to have a complete study of lower

Mars atmosphere and have both been considered as landing sites for future human missions or by other Mars missions in development.

Baseline selection

After trade studies and an iterative process the mission architecture has been divided in two main segments: orbit and Mars surface+lower atmosphere.

The in-orbit fleet will be constituted by 12 CubeSats arranged in four different orbital planes; all the orbits will be circular and polar, with an inclination of 95° and a 200 km altitude. This architecture will guarantee a good coverage of the planet's surface during each Martian day. The payload carried by the orbiters will be cameras, mass spectrometers and radiation sensors. The cameras will allow tracking the dust storms and the formation of clouds, in order to help to characterize their seasonal variations. The mass spectrometers will collect information about the composition and the distribution of the upper Martian atmosphere. Finally, the radiation sensors will gather data about the radiation environment around Mars.

The chosen mission architecture has two other profiles of measurements that require an entry into the Martian atmosphere: these two additional branches are called in this baseline as "CubeSat shower" and "landers". They represent the segment on Mars surface and lower atmosphere. The first one is formed by a series of CubeSats (about 20 units, gathered in groups of 4 or 5 units) which are made to de-orbit in different areas of Mars in order to collect temperature, pressure and wind speed measurements during the descent toward the ground. This will enable the mission to acquire data with an high coverage of the surface of Mars, both from the point of view of latitude and longitude, but also temporally, since it will be possible to make them de-orbit at different times of the Martian year, characterizing its seasons. To collect as much data as possible, landers should be restrained during the descent, so as to extend their measurement life: after reaching the ground, sensors will continue to collect information on atmosphere variations, becoming weather stations on the surface until the exhaustion of their data transmission capacity or the generation of power. This "CubeSat shower" is effective only in the ballistic phase of its components to create a model of the profile variation of the physical properties of the Martian atmosphere, with a vertical resolution otherwise not achievable. The landers form the second part of the ground segment: these are CubeSat sized structures, greater than those presented previously as containing a higher quantity of instrumentation. These components need to reach safely the ground to begin the measurements, for which the descent must be strictly controlled and also the landing zones were chosen in order to avoid areas that are not flat and the various roughness on Mars. After landing, the deployment of instrumentation provides inflation of a balloon in order to make measurements within the chosen altitude of 30 meters. The main feature provided is the repeatability of the measurement: through the balloon and its ability to achieve predetermined heights through the bond with the main lander on the ground given by a special cable, it will be possible to acquire data at different times of the Martian year, but always at the same altitude. The number of lander is reduced to only two units, one for each landing zone (Utopia Planitia and Elysium Planitia) and the type of measurements is different and comprising a large number of aspects of the Martian atmosphere. Only a part of the instrumentation will be embarked on the balloon and flown to the defined heights: these are the probes for pressure, temperature, humidity and wind intensity. The remaining will stay on the ground with the main lander during the entire mission, allowing to collect data about the radiations that reach the Martian surface, as well as those resulting from a mass spectrometer and a sensor for the analysis of dust carried by winds (dust impact sensor).

Every CubeSat, both in orbit and on surface, is expected to communicate only with the mothership and with already existing spacecraft orbiting around Mars. No direct Earth communication or crosslink between CubeSats will be implemented, since both these configurations will require too many complex systems. The two segments previously defined will be able to work in synergy in order to provide a more detailed model for the Martian atmosphere that could be used to plan a future human mission on the red planet.

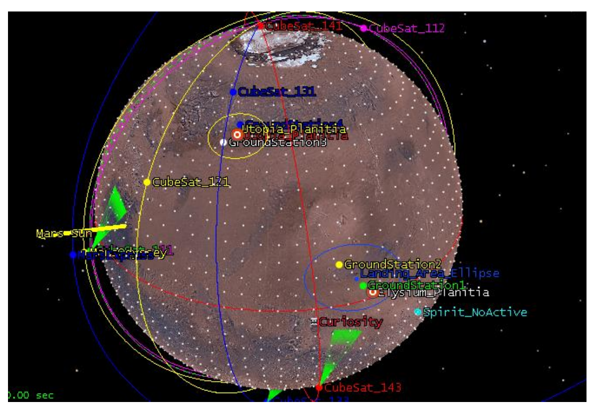

Fig 5: Simulation of the atmosphere sounding mission concept

CONCEPT C: SURFACE BIOHAZARDS

It is fascinating to imagine to land on Martian surface in order to look for presence of life-evidences. It is also obvious that an extensive in-depth analysis of data from the scientific community should be necessary. The main purpose of this concept generation is to find possible solutions to support future human missions. So it is necessary to look for hazards that could create difficulties for a human crew or even to find evidences of past/present life on Mars so that further missions will investigate more accurately on certain landing sites. In order to improve the knowledge of the potential Martian environment in which a mission is expected to find bio-evidences, the team investigated experiments conducted in laboratories worldwide, focusing on experiments in which astro-biologists tried to repeat Martian conditions on Earth. Then it was defined what kind of biohazards the mission may find on Mars and a way to find bio-evidences was investigated too. All information gathered from this phase were useful to investigate the progress the scientific community made, thus better understanding the probability to find life-related evidences on Mars and how to find them.

Work Analysis

The first step consisted of converting the mission statement into a specific objective. In detail, the task were the following: to find life-related molecules on Mars ground using tests, experiments and collecting samples of the Martian soil; to determine if the Martian environments to be contacted by humans are free, to within acceptable risk standards, of biohazards that might have adverse effects on the crew that might be directly exposed.

The team focused on identifying in what ways a fleet of CubeSats could have been of support in a search for organic complex molecules, then on the planet soil and subsurface characteristics, on the achievable landing sites and finally on techniques for soil penetrations. The possibility to look for more molecules using the same instrument resulted in extending the purpose and the length of the mission. In this context it was possible to determine at least five achievable landing sites, sorted by different soil types, chemical composition, latitude, temperature, presence of water.

Three candidate methods for soil penetration methods were assessed: laser, drill, and impact. Four types of optical analyzers for the search for biomarkers were investigated: Raman Spectroscopy, Infrared Spectroscopy, UV Fluorescence, and Capillary Electrophoresis (Mars Organic Analyzer). Useful information to study the soil was collected: maps of ground ice and sub layered ice, maps of average temperature, humidity and atmosphere composition.

Five landing sites were selected (see Fig. 6) after a trade-off based on scientific interest (presence of ice water, atmospheric pressure, etc.) compared with the difficulty of operations (e.g. difficulty of penetration).

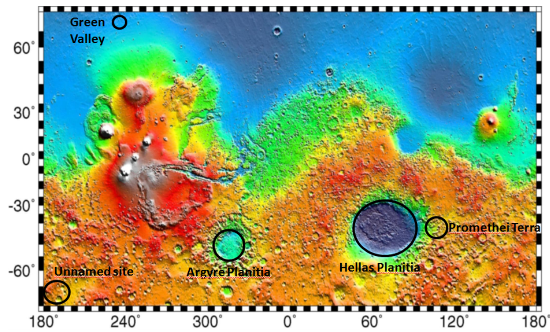

Fig 6: selected landing sites for bio-hazard search

As the penetration methods are concerned, the drilling involves different techniques: force, heat, chemical reactions, and ultrasonic waves. In any case a CubeSat-size system was considered unlikely to provide sufficient force or energy for these solutions. The impact solution with the Space Penetrator System [34] instead seemed very promising at the first glance. Though there have not been successful planetary penetrator missions yet, three systems have been developed and tested on the ground: Deep Space-2 (DS-2), Mars'96 and Lunar-A. Moreover, a lot of work has been done in this field and a great number of new concepts have been developed in the last years. Between the latest mission concepts encountered the idea of penetrator a system providing an alternative way to access the subsurface was interesting: the idea is basically to deliver instrument packages to the subsurface at high speed. This concept have the purpose to take advantage from the high kinetic energy provided by the descent, thus saving weight and power of an heavy decelerator, avoiding as well to carry a complicated drill and all the subsystem needed to sustain its functionality. The truly concern of such a system is to guarantee the survival of the impact. In particular referring to the ESA's Core Technology Programme that has developed the SPS, a 20 kg penetrator 400 mm long and 200 mm wide able to impact the surface at 100 up to 300 m/s. During the test, successfully completed, the penetrator experienced a deceleration of 24 000 g [35]. Such a system can be deployed from carrier, it is designed for hard landing, breaking through ice and regolith (soil) and penetrating to 2-3m depth; instruments might include sample retrieval drill, optical microscope and mass spectrometer.

The necessity of descending on Mars surface in order to fulfill the mission goal was immediately clear and the researches made led to the identification of five landing sites where it is expected to have higher possibilities of finding bio evidences. Landers relatively small, simple and spread across the surface would ensure the capability of exploring all the identified landing sites. The research the group made brought to evidence the necessity of operating during hot seasons both because thicker ice and the highest environmental pressure are expected, which means higher probability for finding water at triple-point conditions (vapor, liquid and ice).

Mission Concepts

The definition of different options led to the creation of three different mission concepts.

The first mission concept concerns the use of five Space Penetrator System SPS that will descend on Mars surface by ballistic fall and penetrate the ground after the impact with the surface. The SPS itself could contain a set of instruments in a CubeSat-form factor (as the ultrasonic drill) needed to sample and make the required analysis. Using five SPS the exploration of the most important landing sites identified by the researches is guaranteed. All the Space Penetrator System involved in Mission Concept 1 will relay on one orbiter that will send all the data to Earth.

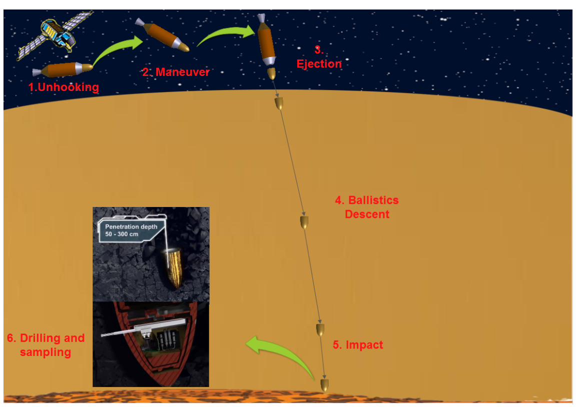

Fig. 7: Mission Concept 1 representation

The second mission concept relates to the use of five landers and two orbiters. The five landers will descend on Mars surface through a controlled landing, achieved by using a parachute and airbags.

The surface will be penetrated using an ultrasonic drill, then samples will be collected and analyzed: data will be sent to the two orbiters and then to the ground stations on Earth. Having two orbiters may assure a better coverage of the landing sites and scientists on Earth should receive data more frequently.

Mission Concept 3 is a mix of the previous ones, considering both penetrators and landers. SPS will descend on Mars surface by ballistic fall and penetrate the ground after the impact with the surface. On the other hand a controlled landing for the landers is required and will be achieved using a parachute and thrusters. Once on the surface the landers will penetrate the ground using a laser drill and both the landers and SPS will collect and analyze the samples. Data will be sent to an orbiter that will transmit them to the ground stations on Earth. Using landers and SPS the exploration of the most important landing sites identified by the researches is guaranteed. Moreover it will be possible to choose to send the SPS in the most demanding landing sites, for example where a deeper penetration is required.

The critical requirements definition process and the comparison with existing systems, which led to the feasibility assessment and a first sizing estimate, helped the team to define some Figures of Merit such as coverage, resolution, communication, lifetime, payload power, size, weight, and cost. As trade-off result, the mission concept 1 was chosen as baseline, in according with mission and scientific objectives and goals, also considering a total autonomy after the deployment phase.

In terms of mission objective the SPS, including the “lab-on-a-chip” and a spectrometer or an ultrasonic drill, should be able to find past or present bio-evidences in the Mars soil with a generically soil analysis, considering a penetration depth from 50 to 300 cm. The mission scenario includes a number of spacecraft equal to the number of landing sites that provide the visit of different portions of Martian surface and taking samples of Martian soil with an autonomous process.

CONCLUSIONS

As part of a research on advanced concepts for future generation of small-satellite missions beyond Earth orbit, the team focused attention on the visionary scenario of networks of CubeSats in support to the human exploration of planet Mars.

The CubeSats-on-Mars-scenarios encompass the perspective of CubeSats as effective tools in support to the envisaged human exploration of Mars’ orbit and surface, and contributes to the long-term vision of Mars exploration. An analysis of the potential environmental hazards and of the precursor measurements necessary to support human operations led to the definition of some primary needs prioritized by NASA MEPAG and P-SAG groups.

With the analysis of different levels of conceivable mission scenarios, this work highlighted the necessity for humans on Mars to have a support from a timely responsive and spatially distributed network of highly disposable, replenish-able, and low-cost satellites.

The unique features of CubeSats when used as distributed systems have been evaluated against the need of precursor global measurements: at least three investigations for three different subjects (orbit, atmosphere, surface) seem to fit promisingly. The cost and technical feasibility of the three concepts will be subject to further investigations.

The study has been carried forward within an exchange program between two research groups at Politecnico and MIT, since January 2014, led respectively by Prof. Sabrina Corpino and Prof. Sara Seager. The MIT team has extensive experience working on the boundary of planetary science and engineering, and contributed to the PoliTo group providing expertise in how to identify science goals for developing scientific missions that can be implemented with CubeSats or small platforms as well as the related science requirements flow down and traceability. The PoliTo research group has expertise in developing technologies for CubeSat and in solving engineering challenges associated with performing high complex mission tasks by using small satellites.

As both groups have a good expertise in small satellite and platforms development for Earth orbits, for us the new ambitious paradigm is represented by a research aimed at studying the capabilities of CubeSats beyond LEO for valuable planetary science missions.

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