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Dry Ice Freezing-Sublimation Energy Conversion for Space Stations, the Moon, and with Particular Reference to Mars

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Consideration is given to the use of CO_2 freezing-sublimation process for energy conversion for spacecrafts, and lunar and Mars human outpost. The idea is conceptually simple: for a space stations, spacecrafts or outpost located at the moon, the drastic changes of temperature between the shadow and isolation time can be harnessed to freeze (during the shadow) and sublimate (during isolation) CO_2 which is properly stored in suitable tank or vessel. Because the huge difference in density between dry-ice and gas, the sublimations could be translate into a strong build up of pressure in the tank when sublimation occurs limited only by the critical point of CO_2 at environmental conditions. Therefore, the depressurization of the tank can generate electricity by sudden adiabatic expansion of CO_2 using, say, a simple turbine and the avoiding loss of efficiency by Carnot considerations when thermal conversion systems are used . Because in outer space (spacecrafts, space stations, etc...) as well as in the Moon there is not available CO_2 and then it must be brought from the Earth, the system must operate in a closed cycle, in which the expansion of CO_2 must be from a pressurized tank to a non-pressurized tank in order to avoid exhaust the CO_2 into environment. This technique, however, reduce the maximum efficiency attainable in the conversion of energy during expansion. However, for Mars, where the atmosphere is nothing but CO_2, the CO_2 can be extracted from the atmosphere and be exhausted which increase the efficiency in the mechanical conversion of energy. Nevertheless, for Mars, the freezing of the CO_2 although could be performed during cold nights, it is possible that a supplementary source of energy will be needed (e.g., Peltier batteries) to help drop temperatures around an additional $\Delta T \approx 20 - 30$ K. Utilizing a simplified geometrical model, the proposed energy conversion method was investigated and theoretical calculations derived and compared with traditional proposed methods. One of the most interesting applications of the proposed technique is in the production of intensive electrical pulses on Mars which can be used in the Sample Fetching Rover (SFR) for Mars Sample return Missions. In fact, the technique could be employed to generate short but powerful electromagnetic pulses for communication between the SFR and the return vehicle (which according with current reference mission could be as far as 150 km each other) and the compensating the strong loss of power of the electromagnetic signal due to the high opacity of the terrain because dust.

Keywords. *Energy systems, Energy conversion,Moon and Mars human settlements,Sample Fetching Rover (SFR).*

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The CAESAR New Frontiers Mission: Returning a Sample of a Cometary Nucleus

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Abstract

The Comet Astrobiology Exploration Sample Return (CAESAR) mission will acquire and return to Earth for laboratory analysis a sample of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (67P). CAESAR will characterize the surface region sampled, preserve the collected sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir.

1. Introduction

Comet sample analyses can provide unparalleled knowledge about presolar history through the initial stages of planet formation to the origin of life. Returning a sample of a cometary nucleus can uniquely address questions regarding the nature of Solar System starting materials and how these fundamental components came together to form planets and give rise to life.

The Comet Astrobiology Exploration Sample Return (CAESAR) mission will acquire and return to Earth for laboratory analysis a minimum of 80 g of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (67P). CAESAR will characterize the surface region sampled, preserve the collected sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir.

The sample CAESAR will return will allow laboratory analyses on Earth to determine the nature and abundances of interstellar dust grains and molecular cloud materials, and characterize the origins and ages of refractory solar nebula condensates. It will trace the history of volatile reservoirs, delineate the chemical pathways that led from simple interstellar species to complex and prebiotic molecules, and constrain the geological and dynamic evolution of the comet. And it will evaluate the potential role of comets in delivering water and organics to the early Earth. CAESAR will achieve these goals by carrying out coordinated sample analyses that will link macroscopic properties of the comet with microscale mineralogy, chemistry, and isotopic studies of volatiles and solids.

2. Implementation

Launched from Cape Canaveral, the solar powered CAESAR spacecraft conducts an outbound cruise, equipped with a solar electric propulsion system. After a flyby of the Earth and possibly the 12-km B-type asteroid 2809 Vernadskij, it arrives at 67P in December 2028. CAESAR enters orbit around 67P, lowering its orbital altitude slowly and sequentially over a period of months.

Collection of a sample from the surface of comet 67P is enabled by the CAESAR Camera Suite provided by Malin Space Systems. During an initial survey, the color Narrow Angle Camera is used to search for natural satellites, determine changes that have occurred since Rosetta, and produce a global topographic map. Images of increasing resolution are used to downselect to 16 and then 8 candidate touch-and-go (TAG) sites. A subsequent detailed survey phase provides images that are used to down-select to the final 4 candidate TAG sites. These sites are documented with 7-color stereo images, and higher resolution monochromatic stereo images. The team selects a primary TAG site. At least three TAG campaigns can be conducted.

Data for TAG guidance is provided by both optical navigation and laser ranging. After a deorbit burn, three deterministic propulsive maneuvers refined by a closed-loop linear correction from an onboard navigation system deliver the spacecraft to the selected TAG site. The sample is collected by the Sample Acquisition System (SAS), which has been specifically designed for the surface properties of comet 67P observed by the Rosetta/Philae mission. It contacts the comet surface during a brief touch-and-go maneuver, mounted on a three-degree-of-freedom TAG Arm. During surface contact, pneumatic jets direct the sample into a 1.5-liter sample container. Sample collection is verified by direct imaging of the sample container interior, and a load cell in the TAG Arm measures sample mass. An engineering model of the SAS has been tested in zero gravity and vacuum at the NASA Glenn Zero Gravity Research Facility, over a range of adverse surface strength properties, slopes, and particle size distributions. Honeybee Robotics provides the SAS.

After sample collection, the spacecraft automatically executes a back-away burn. The TAGCAM camera, mounted on the spacecraft, images the SAS and surface at five frames/s during TAG, documenting TAG at high resolution. The CANCAM camera, mounted within the SAS, images inside the sample container, documenting sample collection. Once successful sample collection has been verified, and while the sample is still cold, the TAG Arm inserts the sample container into the Sample Containment System (SCS), mounted inside the Sample Return Capsule (SRC). The SCS immediately seals the sample, preventing material from escaping into space. The SCS seal uses a stainless-steel knife edge driven into a copper gasket, and has been shown via test to substantially exceed leak rate requirements after having been sealed under a range of cold and dirty conditions. Honeybee Robotics also provides the SCS.

The SCS then slowly warms the sample from the cold temperatures at which it was collected to typical comet surface temperatures near perihelion. As gases evolve from the solid sample, they pass from the SCS into a 5-liter passively cooled gas reservoir in the Gas Containment System (GCS), also mounted in the SRC, separating them from the solid sample and thereby protecting the solid sample from alteration. Once H_2O has sublimated from the solid sample, the GCS is sealed to capture the volatiles it contains, and the SCS is vented to space to maintain the solid sample under vacuum. The SCS vent is closed before Earth entry to prevent atmospheric contamination. Continuous records of sample temperature, pressure, and H_2O vapor partial pressure are collected from sealing at the comet until opening on Earth. The interiors of the SCS, GCS, and associated plumbing are coated with high-purity gold to minimize surface reactivity and catalysis. Goddard Space Flight Center (GSFC) provides the GCS.

The pristine nature of the sample is preserved using stringent cleaning protocols during fabrication, and careful mission design during spacecraft operations. Ground and flight witness materials thoroughly document any contamination. The team follows rigorous cleanliness and documentation protocols through all mission phases. The CAESAR SRC is provided by the Japanese Aerospace Exploration Agency (JAXA). Its design is based on the SRC flown on the Hayabusa and Hayabusa2 missions. Like its predecessors, the CAESAR SRC drops its heat shield during parachute descent, greatly simplifying thermal control of the comet sample. The aerodynamic stability in the transonic regime of the Hayabusa SRC design allows use of a subsonic drogue parachute, providing ease of flight testing.

The SRC lands at the Utah Test and Training Range (UTTR) and is immediately placed in cold storage. Phase change material sealed in aluminum housings mounted on the GCS assures that no melting of H_2O will occur even if SRC recovery is delayed for hours. All recovered hardware is transported to the Johnson Space Center, where the samples are removed and delivered to the dedicated CAESAR curation facility. After preliminary examination, samples are made available to the worldwide scientific community.

3. Summary

CAESAR will return the first sample from a comet nucleus. The payload has been designed to maximize the scientific value of the sample, including both its non-volatile and volatile components. The choice of comet provides substantial risk reduction, achieving the mission within a constrained New Frontiers budget. Most of the sample (≥75%) will be set aside for analysis by generations of scientists using continually advancing tools and methods, yielding an enduring scientific treasure that only sample return can provide.

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Will Europe never have a small body sample return mission?

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1. Introduction

Small bodies, as primitive leftover building blocks of solar system formation, offer a record of the chemical mixture from which the solar system and its planets formed some 4.6 billion years ago. The outstanding success of the ESA Rosetta mission demonstrates the importance of having access to the composition of these bodies. The Rosetta mission has provided unique new insight into the nature of comet 67P/Churyumov-Gerasimenko, but the instruments aboard Rosetta and Philae could not analyse key elements and isotope systems with the detail necessary to establish a precise chronology and investigate the nature of organics to provide the detailed composition of these objects. It is today clear that the major advances in our understanding of the origin of the solar system, and how solar system processes and materials shaped the origin of Life on Earth can be achieved only by obtaining an unaltered sample from a primitive body and analysing it on Earth with the most precise instruments.

2. Present missions

We are in a new era of high international interest in sample return missions. NASA New Frontieres OSIRIS-REx mission will start its close proximity operations to the primitive asteroid Bennu in December 2018 with sample return to Earth in 2023. JAXA has its Hayabusa2 mission at present close to the asteroid Ryugu with a sample return in 2020, and is deeply studying the MMX mission, a sample return to the Martian moon Phobos to be launched in 2024 and return to Earth in 2029, and perhaps even a sample return to Trojans. CNSA is planning several sample return missions, including to the Moon and to Near Earth Asteroids. A new sample return mission to the comet 67P/Churyumov-Gerasimenko - CAESAR (Comet Astrobiology Exploration Sample Return) has been pre-selected by NASA for a one-year study with final selection at the end of 2018 for a possible launch in the mid-2020s.

3. European studies

With the COSMIC VISION 2015-2025 Program, created in 2005, ESA started to study small body missions within the Science and Exploration Programs. Several studies were performed for sample return missions to the Martian satellites Deimos and Phobos and detailed studies were dedicated to sample return from near Earth asteroids in the framework of M-class mission selection.

Marco Polo (ESA/SRE(2009)3) and MarcoPolo-R (ESA/SR(2013)4) have been studied at ESA in their Concurrent Design Facility (CDF) and as phase A studies by several european industries. These studies helped advance key technologies and triggered additional activities developing critical sub-systems. The key sampling and return capabilities, i.e. asteroid navigation, touch and go, sampling mechanism and the re-entry capsule have already all benefited from industrial studies maturing TRL (5-7) and identifying technology development solutions. The NEOShield-2 project, financed by EC (2015-17) in the framework of EU H2020 program, also studied autonomous GNC and IP technology for a Sample Return S/C mission scenario to land on a small asteroid.

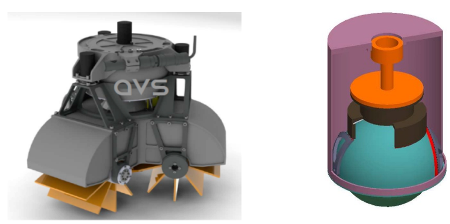

Figure 1: *SATCS Sampling Tools by AVS (left), Selex Galileo (right).*

The detailed study of MarcoPolo-R demonstrated that a dedicated sample return mission to a primitve NEO was entirely feasible and fitted within the M-Class budget of the Cosmic Vision Programme. However, subsequent evolution of the proposal for the M5 launch opportunity (MarcoPolo-M5) was deemed technically or programatically outside the scope of an M Class mission, for some, as yet unknown, reason.

Among the numerous studies carried out by European Industries, examples of the sampling tools are shown in Figures 1 and 2 following dedicated technology activities under the lead of AVS in Spain, Selex Galileo in Italy and Airbus in UK. The tool design is the result of a very large prototyping campaign where many different concepts were looked at and tested, and of modelling of sampling in microgravity. For the Earth Re-entry capsule, the development by Astrium of the "ASTERM" Thermal Protection System material shown in Figures 3 has also been very successful. This material is a lightweight ablative Carbon Phenolic, similar to the US PICA material (Stardust, MSL, Dragon) and has already reached TRL 5 with successful plasma tests in relevant sample return re-entry conditions, with heat fluxes up to 14-16 MW m^{-2} at relevant pressure. It is also to be noted that in order to demonstrate the manufacturability of an ASTERM-based mono-block heat shield, an approximately 7:10 scale front heat shield was successfully built.

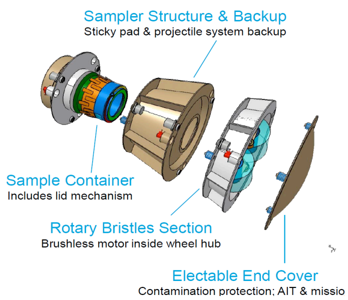

Figure 2. *Different option of sample tool*

4. Curation facility

For any sample return mission, a curation facility is a necessary development. Concerning the European curation, a project called EURO-CARES for European Curation of Astromaterials Returned from Exploration of Space has been financed by the European Commission in the framework of Horizon 2020. The objective of the EURO-CARES project was to create a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility (ESCF). A long-term curation of extra-terrestrial samples implies deep studies to keep the samples as clean as possible from any possible contaminants, while ensuring they remain contained in case of biohazards. The requirements for both high containment and ultraclean facilities and how they could be combined were defined in detail, helping identify the path for the development of a highly specialised and unique facility and the development of novel scientific and engineering techniques.

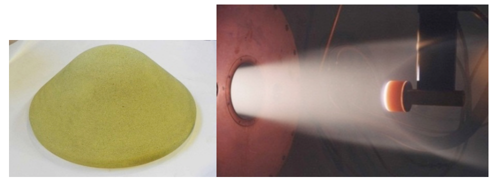

Figure 3: *Heat shield material prototype (left) and heat shield plasma tests in DLR (right)*

5. Conclusion

Near Earth Objects are the most accessible targets containing primitive materials for scientific research missions and some of them are more accessible than the Moon. The NEOShield-2 project allowed characterization of a large number of NEO candidates for space missions. A significant number of NEOs of D-type, particularly appealing for their content in organics and pre-biotic material have been identified at low ΔV (Barucci et al. 2018, MNRS, 476, 4481).

We note that while outside Europe two sample return missions are on the way and several others under study for launch in the next decade, despite all the studies and expertise existing in Europe, despite schools such as the Alpach School devoted to this topic in Summer 2008 and 2018, all past projects have been rejected and none is even considered anymore on this continent! It is legitimate to wonder about this situation.

The current status of some of the key European technologies will be presented and discussed.

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OSIRS-REx@Bennu and Hayabusa2@Ryugu: thermal modelling of sample return mission target asteroids

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1. Asteroid thermal modelling

Asteroid observations in the thermal infrared have been been carried out since the '70s mainly to measure their sizes [1]. Essentially, these observations are obtained from space. Space surveyors such as IRAS [2], MSX [3], AKARI [4], Spitzer [5], and WISE [6] (see also [7]) have provided more than 150,000 asteroid sizes and albedos.

Moreover, thermal infrared observations allow the determination of geo-physical properties of bodies' surfaces. For instance, it is well known that rocks cool off at night more slowly than fine materials (e.g. sand) of the same compositions. This has been used to determine the rock abundance on our Moon [8] and on Mars [9] from night-time thermal infrared measurements.

A physical property that is often derived from infrared measurements is the thermal inertia of the surface [10]. This quantity measures the resistance of a body to temperature changes.. Thermal inertia can be used to estimate to estimate the grain size of the regolith [11, 12, 13], which is crucial information for sampling site selection (e.g. in the case of OSIRS-REx).

In the case of asteroids, thermal inertia controls the strength of the Yarkosvky effect, which is a secular non-gravitational perturbation on the orbit, due to the momentum imparted to the asteroid by the emission of thermal photons [14]. If the variation of the orbital semimajor axis due to the Yarkosvky effect is measured, e.g. by radar or utra-precise optical astrometry, and the body's size and thermal inertia are available, it is then possible to solve for the bulk density of the asteroid [15], which is one of the most interesting, yet unknown, properties to be determined for asteroids.

The value of the thermal inertia, together with the rotation period controls the amplitude of the day-night temperature excursions, which can reach several tens to hundred degrees on airless bodies such as asteroids [16, 10]. These temperature variations can trigger thermal fatigue [17, 18] of the surface materials leading to their failure and the production of fresh regolith.

The arrival of JAXA's Hayabusa2 at the near-Earth asteroid (162173) Ryugu and of NASA's OSIRIS-REx at (101955) Bennu this year will offer the opportunities to perform the aforementioned studies in great details on their target asteroids.

2. OSIRIS-REx & Hayabusa2

NASA's OSIRIS-REx is a sample return mission that will perform detailed infrared observations of the asteroid Bennu using OTES. This is a thermal emission Fourier-transorm spectrometer, built by P. Christiansen and collaborators at the ASU, USA, that collects hyperspectral thermal infrared data over the spectral range from 5.7 to 100 microns. OTES will be used to derive the composition and the thermophysical properties of the surface of Bennu. The main topics that OTES aims at addressing are: (1) to document the sample site spectral and compositional properties; (2) to globally map the composition of Bennu; (3) to determine regolith physical properties, such as grain size, stratification, and (4) to measure asymmetric thermal emission around the asteroid that produces the Yarkovsky effect

On the other hand, JAXA's Hayabusa2 is equipped with a thermal infrared imager (TIR) [19] based on a microbolometer array 320 x 248 pixels that will take images of Ryugu. The pass band of the detector is 8–12 microns and there are no filters. Radiance measurements are converted into temperatures via pre-flight calibration. The goal of TIR is to measure surface temperature, determine thermal inertia [20], and regolith nature. It will also be used for selection of sampling sites and for the location of MASCOT lander touchdown. The latter is also equipped with MicrOmega and MARA. The former will analyse the surface composition at micron -scale resolution; the latter is a radiometer that will measure the surface temperature at the landing site. MARA measurements are planned to be carried out along at least one day/night cycle.

OSIRS-REx and Hayabusa2 also differ in the observations modes: while the former will use different "stations" around Bennu (at 03:20 AM, 06:00 AM, 10:00 AM, 12:30 PM, 03:00 PM, 06:00 PM, 20:40 PM of local time), the latter will mostly observe the subsolar point at nadir, i.e. from zero degree of phase angle.

OSIRIS-REx and Hayabusa2 will provide high quality data to be analysed by means of sophisticated thermal models. In some of these models, team members of these missions are implementing heat transfer taking into account the granular nature of the soil, in order to study the regolith grain size, rock abundance and stratifications.

Acknowledgements

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Solar wind-induced space weathering on asteroid Itokawa

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Abstract

A lesson learned from space weathering studies of Hayabusa-returned regolith particles is that laboratory experiments and expectations are hard to transfer to nature. Time, temperature and small body-dynamics are important factors to consider.

1. Introduction

Orbital perturbations of near-Earth asteroids (NEAs) occur on time scales of several hundreds to thousands of years. Asteroid 25143 Itokawa sampled by JAXA's Hayabusa spacecraft is an Apollo-type NEA with a chaotic orbital evolution [1]. A (partial) record of collisions, tidal strain, changes of spin, and thermal cycling connected to this evolution is potentially preserved in the regolith samples recovered from such bodies, which offer insight beyond remote sensing and numerical modeling.

Space weathering and erosion on atmosphere-less, rocky asteroids are complex processes involving multiple mechanisms that act on different temporal and spatial scales. 'Space weathering' *sensu strictu* as defined by [2] can be understood as the sum of surface modifications that change the optical spectral of individual regolith particles on relatively short time scales (~10^2-10^3 years).

The irradiation of directly exposed mineral surfaces by ions of the solar wind (~1 keV/nucleon, mostly H and He) has been recognized as one important mechanism of space weathering on asteroids [3]. The stopping of energetic ions within dielectric solids leads to structural damage via knocking of atoms from their regular, ordered crystal lattice sites into disordered, interstitial positions. Based on laboratory experiments with silicate minerals, this process should start with the disordering of cations while the anionic sublattice (i.e., SiO_4 tetrahedra) maintains structural coherency for longer time, resulting in partially amorphous rims with preserved crystallographic orientations of crystalline remnants. On the contrary to laboratory experiments and Monte-Carlo simulations predicting rapid amorphization in <10^3 years, the study of Hayabusa-returned samples has shown that ion-induced damage develops at much slower rates [4]. In the case of olivine significant amorphization does not occur even on time scales of ~10^5 years. Instead, olivine develops polycrystalline rims with very little, if any, amorphous material between crystallographically rotated, nanocrystalline olivine domains [5].

2. Samples and Methods

Since 2013 we have studied multiple Hayabusa-returned regolith particles by focused ion beam (FIB) sectioning and analytical transmission electron microscopy (TEM), including the largest particle recovered (RA-QD02-0136, ~310 µm). The sample suite includes all the principal minerals of the LL-chondritic assemblage (Table 1), in order to better understand the behavior of all relevant phases.

3. Results

Seven out of eight particles studied by TEM show rim structures on mineral surfaces that indicate exposure to the solar wind.

Table 1: Hayabusa particles studied at FSU Jena.

Sample	Minerals
RB-QD04-0042	Ol, (Di)
RA-QD02-0115	Ol, Tro, Ap, Mer, Met, (Hx)
RA-QD02-0265	Di, (Ol)
RA-QD02-0136	Ol, Plag, (Di)
RA-QD02-0286	Ol, Tro
RA-QD02-0292	Ol, Tro, (OPx)
RA-QD02-0325	OPx, Tro
RB-QD04-0092	OPx, Ol

Ap: apatite, Di: diopside, Hx: haxonite, Mer: merrillite, Met: metal, Ol: olivine, OPx: orthopyroxene, Plag: plagioclase, Tro: troilite. ( ): present but not exposed.

The silicates olivine, orthopyroxene, and diopside show disordered, polycrystalline rims with crystallographic misorientations on the order of a few degrees. Only albitic plagioclase in RA-QD02-0136 acquired a fully amorphous rim without any evidence of polycrystallinity. The phosphate merrillite developed a marginally discernible rim, while Cl-rich apatite did not develop TEM-visible radiation damage. Both minerals were exposed with olivine which developed a ~35 nm wide polycrystalline rim.

Rim widths range from ~25 to ~110 nm. First signs of vesiculation or blistering due to segregation of implanted gases appear within the polycrystalline rims of olivine and orthopyroxene at rim thicknesses of 50-65 nm in the form of thin, crack-like structures parallel to the original surface (Fig. 1). Only the thickest rim observed (~110 nm in orthopyroxene of RA-QD02-0325) shows well-developed vesicles and a top-most layer with significant amorphous material and nanoparticulate metallic iron ($npFe^0$, ~5 nm).

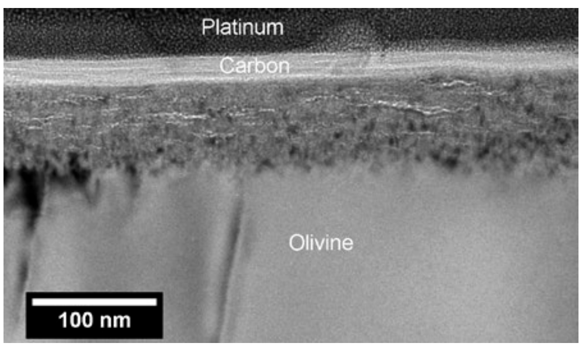

Figure 1: TEM image of crack-like structures in the polycrystalline damage layer of olivine suggesting incipient vesicle/blister formation (RA-QD02-0292).

Rims developed differently on different parts of the particles, indicating that surface were shadowed from the solar wind for some time and that regolith particles experienced movement on the time scales of rim formation. Vapor-deposited coatings are present but usually very thin (few nm).

4. Discussion and Conclusions

The development of polycrystalline rims in nature as opposed to amorphous ones expected from experiments suggest that the ferromagnesian silicates undergo thermally induced recovery of ionization damage while still being irradiated by the solar wind (i.e., thermal activation moves interstitial atoms back to their positions within the preserved anionic sublattice [5]). Nonetheless, this process appears to produce stress - possibly due to implanted gases - which leads to nanoscale subgrain rotation and eventual formation of vesicles. Due to structural aspects plagioclase and phosphates show contrastingly low and high annealing rates, which leads to enhanced and hindered radiation damage, respectively. Plagioclase seems to be particularly vulnerable due to its relatively open framework structure, which may hinder thermal recovery of the original lattice. Besides the realization that irradiation rates are more relevant than doses [4, 5] the surface temperature of asteroids certainly has an important influence on the development of solar wind-induced space weathering.

Acknowledgements

JAXA is acknowledged for providing Hayabusa-returned samples through international A/Os and consortium studies. The FIB-TEM facility at FSU Jena is supported by DFG grant LA 830/14-1 to FL.

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EPSC Abstracts
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European Curation of Astromaterials Returned from the Exploration of Space (EURO-CARES) – A roadmap for a European Sample Return Curation Facility

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Abstract

EURO-CARES (European Curation of Astromaterials Returned from the Exploration of Space) was a three year (2015-2017), multinational project, funded under the European Commission's Horizon2020 research programme to develop a roadmap for a European Extra-terrestrial Sample Curation Facility (ESCF). The ESCF is designed to receive and curate samples returned from Solar System exploration missions to asteroids, the Moon and Mars.

Introduction

So far there are only two sample receiving and curation facilities dedicated to samples returned from space missions to Solar System bodies - the NASA Johnson Space Centre in Houston (USA) and the JAXA Hayabusa curation facility in Sagamihara (Japan). Previous studies for an ESCF were either country-specific or mission/target-body specific. With the EURO-CARES project have progressed from these specific studies by incorporating and rationalizing relevant expertise and experience from a variety of individuals and institutions around Europe and the world. These include both NASA and JAXA, various laboratories and museums that curate meteorites, biosafety laboratories, cleanroom manufacturers, electronics and pharmaceutical companies, nuclear industry and the aerospace industry etc.

A challenge in the EURO-CARES work was to design a roadmap for an ESCF capable of receiving and curating samples from both ‘unrestricted’ and ‘restricted’ sample return missions. The requirements for a combined high-containment and ultraclean facility will naturally lead to the development of a highly specialized and unique facility that requires the development of novel scientific and engineering techniques.

The EURO-CARES team work was organized around five technical Work Packages (Planetary Protection, Facilities and Infrastructure, Instruments and Methods, Analogue Samples and Portable Receiving Technologies), led by scientists and engineers from leading institutions across Europe. Along with the scientific and technical aspects and resulting recommendations, the EURO-CARES project also developed on a high impact public engagement plan. More details about the project, the specific Work Packages and their results can be found here: http://www.euro-cares.eu/home.

Recommendations

Europe has curated samples of extraterrestrial material for over 200 years, ever since first recognition that stones falling from the sky were valuable objects for scientific investigation. Europe has an extremely strong and internationally-recognised community of scientists and engineers that specialise in study of extraterrestrial materials their terrestrial analogues, and in handling and containment of biologically-sensitive material. The combination of skills and knowledge ensures that Europe is strongly placed to curate samples collected by the next generation of sample return missions, including material from asteroids, the Moon, Mars and other restricted targets. We do not make recommendations about the location of the facility. That decision is dependent on considerations beyond the scientific and technical, and was not part of our mandate. The facility is likely to cost from in the 10s M Euros for a basic curation facility for unrestricted samples, to > €100M for a bespoke facility for Mars Sample Return. To put this into context, current sample return missions to asteroids (e.g. Hayabusa 2 and OSIRIS-Rex) are costed in the 100s of millions of Euros and a Mars Sample Return mission campaign is likely to cost billions of Euros. Hence the cost of any curation facility will make up a very small part of the overall budget of these exploration missions. In addition, we expect that the facility can be used for all future sample return missions with European involvement, and so the burden on a single mission or funding agency is diminished.

Our major recommendations are:

1. There is an urgent need to update the Planetary Protection Protocols. We strongly recommend a cross-European effort with significant international participation to update the Planetary Protection protocols, utilising the significant expertise in the life and Earth sciences as well as analytical instrumentation innovation that exists within Europe.

2. Funding for a European Sample Curation Facility must be budgeted. Given we anticipate that the required time to build an ESCF is a minimum of 7 years, and perhaps longer in view of the administrative barriers that must be overcome, it is essential that a funding line for an ESFC is identified as soon as possible. We strongly recommend that a European Sample Curation Facility becomes part of the ESFRI roadmap.

3. Appropriate training of staff working in the facility is critical. The amount of time required should not be underestimated and is a major part of the 7 year (minimum) facility development time. We also have a need to promote links between European researchers and combine efforts around Europe to take advantage of complementary skill sets and expertise and to avoid duplication of work or knowledge gaps. We strongly recommend that a training programme for curators is established.

4. There are several complementary activities involving terrestrial analogues in Europe that have a direct link to curation facility development. We recommend that a well-defined and fully characterised suite of analogue materials is assembled for the ESCF before the arrival of material returned from space.

5. As the major European space agency, ESA should be a leading stakeholder in the curation effort, enabling technological development and scientific studies to oversee work undertaken and to develop products that match their future space mission requirements. Individual national space agencies also have their own priorities and bilateral agreements with other space-faring nations.

6. We considered various building designs in terms of separate functional units, each one with its own purpose, such as curatorial space, communications, analogue samples etc. This maximises flexibility and allows for growth of the facility as more missions are returned to Earth. We recommend that the building that houses the ESCF is built as a series of modules, to maximize flexibility.

7. We considered six potential landing sites, and the strengths and weaknesses of each in terms of weather, accessibility and population. From our work, the best site for landing a European sample return mission appears to be the Esrange Space Center, Sweden. However, specific considerations for each individual mission may favour another site.

8. Early characterisation of the samples returned must be undertaken in the ESCF as part of curatorial best practice, and in view of the requirements for handling restricted samples. However, to the extent possible given potential planetary protection constraints, we recommend that detailed examination of returned samples is undertaken by specialists outside the ESFC. This enables the broader science community to engage in the missions and is more cost effective, as it negates the need for multiple large laboratories.

9. Engagement with the public and with decision makers is essential for the ongoing support of the facility. Methods for outreach, education and communication with the public should be at the heart of the ESCF. We recommend continuation of a public awareness programme based on the resources that we have developed.

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EPSC Abstracts
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Planetary Sample Analysis Laboratory (SAL) at DLR

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Abstract

Building on the available infrastructure and the long heritage DLR is planning to create a Planetary Sample Analysis laboratory (SAL) which can be later extended to a full Sample Curation facility. The step-wise extension follows the successful development approach used for the Planetary Spectroscopy Laboratory (PSL) and Astrobiology Laboratories. The goal is to test and validate each extension step before planning the follow-up step. The first step is focused on analyzing samples from the Hayabusa 2 mission.

1. Introduction

Global reconnaissance of planetary surface can only be obtained by remote sensing methods. Optical spectroscopy from UV to far-infrared is playing a key role to determine surface mineralogy, texture, weathering processes, volatile abundances etc. It is a very versatile technique, which will continue to be of importance for many years to come. Providing ground truth by in-situ measurements and ultimately sample return can significantly enhanced the scientific return of the global remote sensing data. This motivates the planned extension of PSL with a PSA laboratory by support of the Astrobiology Laboratories.

PSA will focus on spectroscopy on the microscopic scale and geochemical and geo-microbiological analysis methods to study elemental composition and isotopic ratios in addition to mineralogy to derive information on the formation and evolution of planetary surfaces, search for traces of organic materials or even traces of extinct or extant life and inclusions of water.

The DLR SAL will be operated as a community facility (much like PSL), supporting the larger German and European sample analysis community

2. Current facilities

PSL at DLR (http://s.dlr.de/2siu) is the only spectroscopic infrastructure in the world with the capability to measure emissivity of powder materials, in air or in vacuum, from low to very high temperatures [1-3], over an extended spectral range. Emissivity measurements are complimented by reflectance and transmittance measurements produced simultaneously with the same setup. It is the ground reference laboratory for the MERTIS thermal infrared spectral imager on the ESA BepiColombo mission [4, 5]. Members of the PSL group are team members of the MarsExpress, VenusExpress, MESSENGER and JAXA Hayabusa 2 missions [6]. For the latter mission PSL has performed ground calibration measurements. In addition PSL has been used extensively in support of the ESA Rosetta mission. The samples analyzed at PSL ranged from rocks, minerals, to meteorites and Apollo lunar soil samples.

In a climate-controlled environment PSL operates currently three Fourier Transform Infrared Spectrometer (FTIR) vacuum spectrometers, equipped with internal and external chambers, to measure emittance, transmittance and reflectance of powdered or solid samples in the wavelength range from 0.3 to beyond 100 micron.

In addition the institute is operating a Raman micro-spectrometer lab (http://s.dlr.de/e49q) as part of the Astrobiology Laboratories with a spot size on the sample in focus of <1.5 µm. The spectrometer is equipped with a cryostat serving as a planetary simulation chamber which permits simulation of environmental conditions on icy moons and planetary surfaces, namely pressure (10-6 hPa – 1000 hPa), atmospheric constituents, and temperature (4K – 500K). The samples, which are analyzed in the laboratory range from minerals, Martian analog materials, meteorites, biological samples (e.g. pigments, cell wall molecules, lichens, bacteria, archaea and other) to samples returned from the ISS (BIOMEX) [7, 8, 9] and the asteroid Itokawa (Hayabusa sample).

A sample preparation facility with a highly experienced lab technician and an extensive collection of analog materials and a large spectral database complement the equipment. Sensitive samples are stored in humidity-controlled environments with the option of nitrogen purging. Samples can be prepared in many ways, to match the wide range of techniques offered at PSL and the Astrobiological Labs. This includes producing grain size fractions as well as pressed pellets. Stereo microscopy as well as XRD (X-ray diffraction) analysis is used to characterize the samples before and after preparation as well as after measurements under different temperature conditions. Raman spectroscopic measurements can be performed before, during and after experimental planetary simulation.

All laboratory facilities undergo regular evaluations as part of the DLR quality management process. The evaluations address laboratory protocols, documentation, safety, data archival and staff training.

PSL is a community facility as part of the "Distribute Planetary Simulation Facility" in European Union funded EuroPlanet Research Infrastructure (http://www.europlanet-2020-ri.eu/). Through this program (and its predecessor) over the last 6 years more than 40 external scientists have obtained time to use the PSL facilities. PSL has setup all necessary protocols to support visiting scientist, help with sample preparation, and archive the obtained data.

3. Planned extension

The goal of the first step is the preparation to receive samples from the Hayabusa 2 mission. The current facilities are operating in climate-controlled rooms and follow well-established cleanliness standards. The SAL will be housed in an ISO 5 clean room, with one or two supporting clean rooms for sample handling, preparation and storage. The cleanrooms are equipped with glove boxes to handle and prepare samples. All samples will be stored under dry nitrogen.

To characterize and analysis the returned samples the existing analytical capabilities will be extended and complemented by the following capabilities:

1. Electron Microprobe Analyse (EMPA) for elemental analysis
2. Laser ablated inductive coupled Plasma Mass Spectrometer for elemental and isotope analysis
3. Dual Source TXRF & Grazing Incidence ED-XRF for mineralogical and structural analysis
4. Upgrade of the Fourier-Transform-Spectrometers with an IR-microscope to extend spectral analysis to the sub-micron scale
5. Supporting equipment incl. microtome to prepare thin sections, optical polarization microscope, etc.

Based on current planning the SAL is operational and ready for certification by end of 2021. Analysis of first Hayabusa 2 samples will start by beginning to mid of 2022.

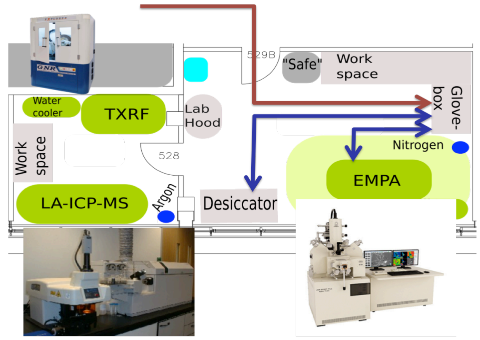

Figure 1 Current layout for the SAL

4. Outlook

Currently DLR is planning a Planetary Sample Analysis Laboratory. Following the approach of a distributed European sample analysis and curation facility as discussed in the preliminary recommendations of EuroCares (http://www.euro-cares.eu/) the facility at DLR could be expanded to a curation facility. The timeline for this extension will be based on the planning of sample return missions. The details will depend on the nature of the returned samples. Through the BIOMEX project a collaboration has been established with the Robert-Koch Institute (RKI) (http://www.rki.de) for question of samples that might pose a bio-hazard. RKI is operating BSL 4 facilities, which might be used as part of the DLR curation facilities.

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EPSC Abstracts
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An analysis of the components of the RITD and evaluating alternatives for each component

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Abstract

To collect soil samples from the Mars and bring them back to the Earth a re-entry concept of a landing vehicle must be developed which is fesabale for the Martian conditions as well as for the Earth. This research shows an entry, descent and landing system that has been already developed for the Martian atmosphere and which is adopted to the Earth's atmosphere. Since the parameter of the Earth's atmosphere are different to the Mars, some adjusting must be done but the overall concept is feasible which has been proved already. To develop the best possible concept, some alternatives will be presented and evaluated. The main components will be listed and the current realization of those components will be shown as well as alternative possible solutions. These solutions will be evaluated in the end.

1. Introduction

Different technologies have been developed to collect samples from the Mars and bring them back to the Earth. To realize this, a re-entry, decent and landing module must be developed. This module must meet Martian and Earth requirements.

An entry, descent and landing system (EDLS) was already developed by the MetNet team. This was an inflatable system which makes the touch down on the Mars possible. The continuation of this project was the Re-entry: Inflatable Technology Development project (RITD) which adopted the EDLS on the Earth's atmosphere. A first concept was already developed and presented before. This research should optimize the RITD project and deepen existing concept.

To optimize the existing concept, a systematical approach will be presented in this paper. Based on Lindemann [1], first of all the RITD will be split in each component. In further steps, different requirements on the RITD will be defined. For each component, different alternative concepts will be presented and evaluated. These alternatives will be compared to the existing concept and finally the best concept, which meets the requirements best, will be proposed to continue the project. The goal of this project to develop a small and light (20 – 50kg) re-entry vehicle on the earth [2, 3]

2. State of technology

The entry, descent and landing system (EDLS) was already developed between 2001 and 2009 by the MetNet team and Finnish Institute of Technology (FIM). This developed vehicle was supposed to land on the Mars. The vehicle's breaking process was engineered as an inflatable system. The advantages of the inflatable system were on the one hand the huge mass reduction because heavy shields are not necessary anymore, and on the other hand, the vehicle can be designed a lot smaller than before, since the shields do not occupy as much space as before. [4]

The Russian Bauman Moscow State University (BMSTU) boarded on the project and developed together with the FIM the continuation of the EDLS which adopted it to the earth's atmosphere and named it re-entry: inflatable technology development (RITD). The conclusion of this project was that this inflatable breaking system is adoptable for the earth's atmosphere with some little modifications. [5-7]

Requirements that were focused on the RITD were based on Finchenko [8]:

- the impermeability with respect to the gas
- Integrity after any repeated folding
- Tightness and integrity from the moment of entering the atmosphere until the moment of landing

- No distortion of the CA shape due to thermal effects
- Materials should not have the property of self-burning after termination of external heat flow

In addition to that, an overall cost requirement will be set up for the evaluated alternatives.

In figure 1, the main components of the RITD are listed based on Harri, Pellinen [9]:

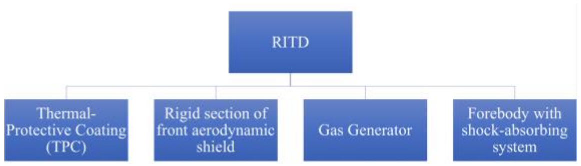

Figure 1: Components and current solution of RITD

3. Method

To approach different potential alternative concepts, a systematical approach will be followed. First of all, the components are analyzed deeply. Afterwards, a brainstorming to reach different potential solutions for each component was realized. These solutions were structurally organized. In the next step, each potential solution for each component is evaluated according to the defined requirements in the chapter before. Tests, simulations, calculations, etc. were used to evaluate the components/functions regarding to those requirements. Before accepting it as an overall solution, no conflicts between each best sub-solution must be ensured.

4. Results

The following figures show the results of two main different concepts. One concept considers a solid body and the other concept considers the inflatable breaking concept.

The figure above shows the pressure (q), the angular velocity of descent relative to the longitudinal axis of the apparatus (ω_x) and the resonance frequency (ω_{rez}) as a function of flight time.

Figure 3 presents the plots of spatial angle of attack (αs), as well as transverse load (qs) for the landing vehicle as solid body in the presence of a set of structural asymmetries (Δy0 =0.001, Ixz0 =0.001, mz0=0.002.).

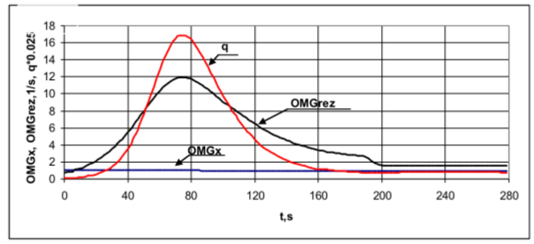

Figure 2: Consider the motion parameters of the landing vehicle as a solid body

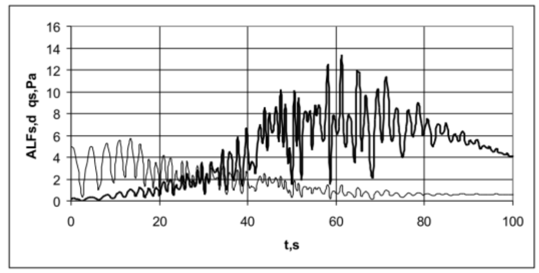

Figure 3: Landing vehicle as solid body in the presence of a set of structural asymmetries

Figure 4 shows a fixed transverse load q_{sf} = 50 Pa an additional value of aerodynamic coefficient of the moment caused by the inflatable braking device exterior shape m_{af} = 0.020.

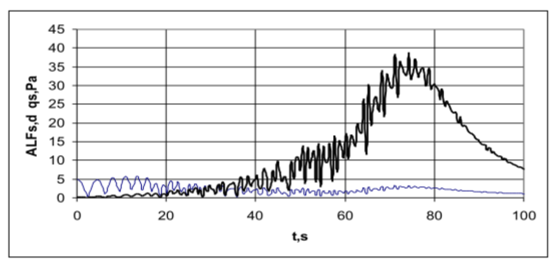

Figure 4: Variation in time of spatial angle of attack and transverse load of the inflatable landing vehicle

The figure above shows the changes in the spatial angle of attack in the presence of complex structural asymmetries and the additional value of the aerodynamic torque coefficient of distortion of the external form of inflatable braking device m_{af} = 0.024 for fixed lateral load q_{sf} = 50 Pa.

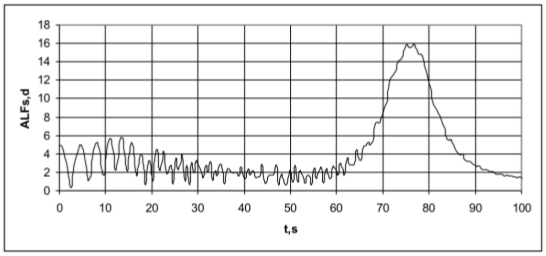

Figure 5: Changes in the spatial angle of attack in the presence of complex structural asymmetries

5. Discussion

It can be seen that under the conditions of an inflatable braking device with m_{af} = 0.024 for fixed lateral load q_{sf} = 50 Pa the solid angle of attack increases indefinitely and landing vehicle loses stability of angular motion.

Thus, depending on the lateral stiffness of the inflatable braking device, the landing vehicle can be both stable and unstable character of angular motion.

However, in this part of the trajectory the value of the velocity head is ten times less than its maximum value, so the presence of strain inflatable braking device leads to a small additional increase in the spatial angle of attack.

6. Conclusions

Since already mentioned, this inflatable braking device, originally developed for Martian atmosphere, can be used for terrestrial conditions. Moreover, the braking device deformation leads, on the one hand, to change the values of aerodynamic coefficients of axial force, the normal force in the plane of the solid angle of attack and the stabilizing of the moment. On the other hand, it leads to the appearance of additional small asymmetry in the form of a lateral displacement of the center of mass, moments of inertia, centrifugal and the asymmetry of the form.

Furthermore, the asymmetry of the external form of braking device in its deformation can lead to significant values of the coefficient of aerodynamic asymmetry. This in turn causes a change in the dynamics of angular motion of the landing vehicle. It is necessary to avoid the occurrence of such modes of motion of the landing vehicle.

Last but not least, the proposed method of investigation of the effect of deformation inflatable braking device on the dynamics of the angular motion of a space capsule enables the design phase to determine the required lateral stiffness of the braking device, which provides steady movement of various space landing vehicle on the entire trajectory of descent.

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EPSC Abstracts
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Analysis of Results of Scaled Parachute High Altitude Deployment Test

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Abstract

The parachute subsystem is an important part of rover. The function of the parachute is to decelerate the rover further, for providing good initial conditions for the later process of powered descent.High-altitude parachute opening test conducted on Earth can obtain the test data closest to the real conditions and verify system performance closest to the real conditions.The purpose is to verify the correctness of the technical scheme and obtain the test data. It is necessary technical reserves for future full-scale parachute test.

The test objectives are to verify the inflatable and drag performance of the scale parachute under supersonic and low density conditions, and to provide data support for parachute simulation.

Five flight tests were conducted totally in the test. The test data of Mach 1.3 to 2.4 and attack angle 0~10° of parachute deployment were obtained. This paper describes the test briefly, and analyses the test results mainly, including the curves of the height, speed, Mach number, dynamic pressure, parachute ejection load, parachute deployment load, angle of attack and other parameters along with time. The parachute drag coefficient and deployment dynamic load coefficient are calculated. The results show that the dynamic model used by parachute design is correct, and the technological scheme of probe parachute deceleration system is feasible.

The test process is shown in Fig.1. The carrier platform is a rocket launcher.The rocket is fixed on a launcher, adjusted to the angle of launch. The measurement and launch control device checks the rocket and sends launch instruction. After firing, the rocket flies according to scheduled trajectory, and carries the parachute and the ejecting gun to high altitude. Then the rocket head is separated from the booster. When it comes to the supersonic, low-density and low-pressure conditions, the parachute is ejected. Then the parachute inflates, be filled, descends and lands carring the rocket head. During flight, the measuring devices on the rocket measure and record test data in real time, and transfer the data to the ground telemetry receiving equipment. In the meantime, the trajectory of the rocket head is measured.

The scale parachute is a disk-gap-bank parachute with nominal area of 30 m2. Because parachute is made of special textile materials, it is impossible to realize geometric similarity strictly, but only to extremely. Compared with the full-size parachute, the scale parachute has the same type, the same area ratio of disk, gap and bank of the canopy, the same length ratio of line, and the same structure air permeability.

The scale parachute is placed in the ejecting gun, which is designed according to the space of the platform and the volume of the parachute. The basic structure and design scheme are the same as those of the full size. The length-diameter ratio is similar to the full size. The ejection velocity is calculated by the same method. In addition, compared with the full-size parachute, the Mach number can cover the Mach number of the full-size parachute, and the Reynolds number and the ballistic coefficient are similar to the full-size.

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Chang'E-5 returns to (and from) the Moon: Geological characterization of the northern Ocean Procellarum landing area

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1. Introduction

China Chang'E-5 (CE5) mission, scheduled to launch in 2019, will be the first mission to return samples from the Moon since Luna 24 more than 40 years ago. CE5 is designed to bring back up to 2 kg of lunar samples, using a robotic sampling device and an automatic rendezvous and docking with the return module in lunar orbit, before flying back to the Earth. The CE5 lander will be equipped with a robotic arm and drill core that will allow sampling up to a 2 m depth [1]. The selected landing region for CE5 is located within the northern Oceanus Procellarum, between 41-45°N in latitude and 49-69°W in longitude, and is referred to as the Rümker region [2]. The landing region is spreading north of Mons Rümker itself, a volcanic complex containing multiple domes [3]. The present study reports on the geology of the landing area, proposes landing/sampling sites, and evaluates the potential scientific outcomes of the mission.

2. Datasets and methods

A wide range of orbital data were used to characterize the morphology, mineralogy and composition of the landing area and to produce an updated geologic map [2]. The data collection includes Kaguya TC morning maps and DTM (at 10 m/px), LROC WAC (100 m/px) and NAC imagery (up to ~0.5 m/px), Kaguya MI multispectral data and derived FeO and TiO_2 abundances (following the method of [4]), and M^3 VNIR hyperspectral data, processed with the method of [5].

3. Geological characteristics of the landing region

The Rümker region was found to be relatively flat (Mean slope of the area is 1.1° at a baseline length of 354 m, with only 10% of the area exceeding a slope of 2°), and is lying at an average altitude of -1300 m (Figure 1A, [2]).

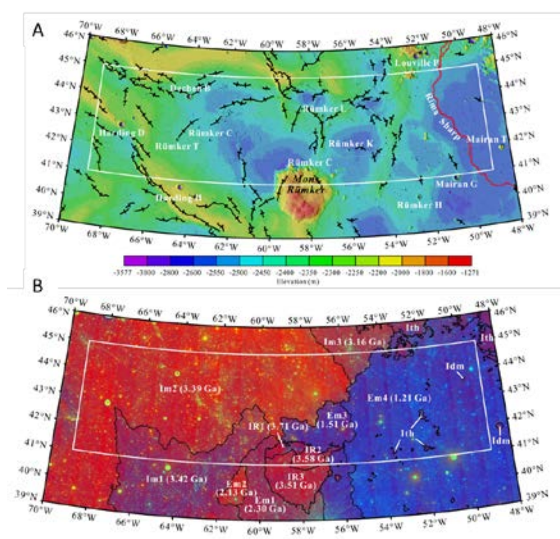

Figure 1: A- Topography of the Rümker region. White box = Selected CE5 landing region; Black lines = wrinkle ridges (Background= LOLA + Kaguya TC merged hillshade superposed on the TC DTM data). B- Geologic units of the Rümker region, superimposed on a MI RGB color composite with bands 750 nm/415 nm as red, 750 nm/950 nm as green and 415 nm/750 nm as blue. (Lambert conformal conic projection; Figures from [2]).

The region is covered by mare basalts which can be subdivided into 7 geological units according to the compositional and mineralogical data (Figure 1B, [2]). The eastern mare units (Em 1 to 4) are characterized by higher FeO (16-18 wt.%) and TiO_2 (6-7 wt.%) contents and a higher albedo, whereas in the western mare units (Im1, Im2, Im3), FeO (14-17 wt.%) and TiO_2 (1-2 wt.%) abundances are lower. M^3 data show that the Rümker region is dominated by pyroxene signatures overall, but slight variations are observed throughout the various units. Spectra of the western mare units are diagnostic of pyroxenes of intermediate composition (such as pigeonite) whereas the shift of VNIR absorptions towards longer wavelengths in the eastern mare units suggests the presence of high calcium pyroxenes (such as augite and/or diopside). The model ages of these geologic units were estimated using standard CFSD methods. Results show that the western part of the Rümker region is much older (~ 3.42-3.16 Gy) than the eastern part (~ 2.30-1.21 Ga). Unit Em4 has an absolute model age of 1.21 Ga, which is the youngest geologic unit in this region, and is one of the youngest mare unit on the Moon [6].

The Rümker region is crossed by several wrinkle ridges, with large and long ridges being more common in the western part of the landing region (Figure 1A). The Rümker region is also marked by the presence of sinuous rilles (e.g., the Rima Sharp, ~1 km in width and 20-50 m in depth [7]). Kipukas (likely remnants of highlands material, unit Ith in Figure 1B) are observed through the region, especially in its eastern part, and are spectrally distinct. A variety of other landforms can be identified in the Rümker region, and were mapped as additional geological units [2]. The most prominent feature is Mons Rümker (units IR1, IR2, IR3 on Figure 1B), a 70 km diameter circular volcanic complex that is ~500 m higher than the surrounding mare surface and spectrally distinct. Mons Rümker is formed by numerous steep-sided domes and shallow domes that likely represent different stages of volcanic activity [3]. In addition, a small-scale (3 km wide, 170 m high), relatively steep, unnamed dome is observed at 49.85W, 43.68N (unit Idm, Figure 1B), in proximity of the Mairan silicic domes [8], and could represent an opportunity to sample evolved volcanism on the Moon.

4. Proposed landing/sampling sites

Young high-Ti basalts appear as an obvious preferred landing site for CE5. Collecting lunar samples from this region could help answer many fundamental, unresolved questions in lunar science. For example, 1) the radiometric age of the young basalt could be used to compare with the CSFD ages to constrain the impact cratering flux of the Moon and other planets, 2) their mineralogy and geochemistry could provide information on the mantle properties and thermal state at this time, and further constrain the lunar thermal history; 3) volatile components in glass and pyroclastic rocks could provide direct clues of mantle properties; 4) Th distribution and contents could improve our knowledge about the role of Th in the late-stage mare basalt petrogenesis [2]. In addition, unit Em4 flat topography offers the possibility of a safe landing. The presence of domes of potentially evolved composition in both Mons Rümker and the eastern part of the landing region adds on to the potential science benefits of the mission, with the possibility to study potential silicic composition of the Moon.

Acknowledgements

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Use of the correlation matrix approach to define the life detection techniques in a sample curation facility

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Abstract

EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space) was a three year (2015-2017), multinational project, funded under the European Commission's Horizon 2020 research programme to develop a roadmap for a European Extra-terrestrial Sample Curation Facility (ESCF). If the samples are brought back to Earth from bodies where there is the possibility of presence of extant or extinct life, there are a wide number of proposed approaches on the techniques to use in order to investigate the presence of biosignatures: [3], [4], [5], etc. All the studies lead to a proposed list of techniques suitable for life detection along with details about the field of application, their efficiency and limits. What is missing is a critical approach able to make a comparison between the techniques in terms of effectiveness, to find a prioritizing ranking. In this paper a quality engineering tool approach, the correlation matrix, was used to support the choice of the techniques for life detection, [1], [2]. The challenge was to analyze and evaluate every technique. To do it, a wide panel of expert was involved. Experts in the following scientific and technological field composed the team: process engineering, mechanical engineering, biology, astrobiology, chemistry. The paper shows how, using a logical flow of analysis, it was possible to identify the critical issues and to highlight the priorities.

1. Introduction

The major drivers we took into account were to define which techniques are really important and which can be considered as optional, rationalize the activity flow inside the curation and provide a support for the design choices of the curation.

Starting from this idea, we focused on the building of a correlation matrix where to correlate the biosignatures with the available techniques. It is known that a number of techniques can detect each biosignature and, at the same time, each technique can be applied for a number of biosignatures. Using the correlation matrix method it is possible to summarize all this information at a glance. It is also possible to give an extra-value to the matrix, trying to be more critical: the idea is not only to determine the correlations between the biosignatures and the techniques, but also to define how strong is each correlation.

2. The correlation matrix

The correlation matrix (Figure 1) shows the correlation between biosignatures and the life detection techniques. According to the matrix approach, the biosignatures were organized per area (morphological, chemical, biochemical, isotopic analysis, and mineralogical), an importance value was given to each techniques, in a range from 1 to 4, and a correlation value was defined, in an exponential range from 0 to 9: 0 if no correlation exists, 1 (low correlation) if the technique is no specific for the biosignature but still usable and/or with medium/low resolution, 3 (medium correlation) if the technique is suitable for the biosignature, although not specific, and/or with medium resolution and 9 (high correlation) if the technique is very specific technique for the biosignature, with high resolution. An extra value was given to disentangle destructive and non-destructive techniques, (1 if the technique is destructive, 1.1 if partially destructive, 1.2 if partially destructive/non-destructive, 1.3 if non-destructive). The numerical results obtained from the correlation matrix are the biosignature occurrence (number of times that the each biosignature is detected by a different techniques), the techniques occurrences (the number of biosignatures that can be detected by a single techniques), the technique mean value (the technique mean correlation with the detected biosignatures) and finally the technique importance rating calculated, for each column (technique), as the sum of the products of the biosignatures importance, the correlation value and the non-destructive/destructive coefficient.

TECHNIQUES	Morphological: Size of single cell - Size of targets	Morphological: Numbers of single bacteria - Number of targets	Morphological: Population size (colonies)	Chemical: Chemical composition	Chemical: Chirality	Chemical: Organic molecules	Biochemical: DNA, RNA	Biochemical: Organic pigments	Biochemical: Protein	Isotopic analysis: Isotopes, Isotopologues	Isotopic analysis: Isotopomers	Mineralogical: Elemental analysis	Mineralogical: Structure, Mineralogy	TECHNIQUES OCCURRENCES	TECHNIQUES MEAN VALUE	TECHNIQUES IMPORTANCE RATING	NON DESTRUCTIVE/DESTRUCTIVE COEFFICIENT	TECHNIQUES IMPORTANCE RATING (*ND/D)
IMPORTANCE	4	4	2	4	4	4	4	4	4	3	2	4	4					
Optical microscopy	9	9	9										3	4	7,5	102	1,3	133
Electron microscopy - SEM	9	9	9											3	9,0	90	1,1	99
GC-MS				9	9					3				3	7,0	81	1	81
LC-MS				9	9									2	9,0	72	1	72
MALDI-TOF				9	3			3	9					4	6,0	96	1	96
Fluorescence microscopy	3	3				9							1	4	4,0	64	1,3	83
Raman spectroscopy						9		9					3	3	7,0	84	1,2	101
High Performance Liquid Chromatography (HPLC)						9		3						2	6,0	48	1	48
Polymerase Chain Reaction (PCR)							9							1	9,0	36	1	36
Enzyme-linked immunosorbent assays (ELISA)							9		9					2	9,0	72	1	72
Fluorescenct in-situ hybradization (FISH)							9							1	9,0	36	1	36
Sequnecing							9		9					2	9,0	72	1	72
Chromatography					1			9						2	5,0	40	1	40
Protein microarray / Marker Chip									9					1	9,0	36	1	36
SIMS						1				9				2	5,0	31	1	31
Isotope Ratio Mass Spectrometry (IRMS)										9				1	9,0	27	1	27
13C-NMR											9			1	9,0	18	1,3	23
SEM-EDX						1						9	1	3	3,7	44	1,1	48
XRF						1						3	9	3	4,3	52	1	52
X-Ray CT													9	1	9,0	36	1,3	47
XRD													9	1	9,0	36	1,3	47
Electron microscopy - TEM	3	3	3			3								4	3,0	42	1,3	55
NMR				1	1									2	1,0	8	1,3	10
FTIR				3		3		1		1			3	5	2,2	43	1,3	56
Marker chip with antibody						3								1	3,0	12	1	12
Capillary Electrophoresis (CE)								3						1	3,0	12	1	12
MC-ICP-MS										3				1	3,0	9	1	9
BIOSIGNATURES OCCURRENCES	4	4	3	5	5	9	4	6	4	5	1	2	8					

Figure 1: biosignatures/techniques correlation matrix.

3. Main results

Starting from the numerical results it is possible to make some observations: the initial list included 27 different techniques but the he number of high-correlation techniques are 21; there are 8 techniques able to detect 2 or more biosignatures; if only high-correlation techniques are considered, the minimum number of techniques needed to detect all the biosignatures is 9. This number decreases to 7, if also the medium correlation techniques are considered; if only the high-correlation techniques are considered, the minimum number of techniques needed to solve all the high-importance (given value 4) biosignatures is 7, and this number decreases to 6 if also the medium correlation (given value 3) techniques are considered.

4. Summary and Conclusions

The proposed correlation matrix technique is a powerful tool able to convert a subjective approach to an objective one, helping to rationalize a problem from the boundaries definition to the final solution. The matrix allows to select the most important techniques. This leads us to define the procedures to be performed inside the ESCF, which are strictly related to the techniques. Starting from the obtained results it is possible to facilitate the design choices: choosing a technique allows a better evaluation of curation dimensions (depending on the size and position of the instrument, etc.) and layout (depending on its position, the compatibility with other instruments, the need of ancillary systems, etc.).

Acknowledgements

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Mars Sample Return Science—How Should it be Organised Into Objectives?

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Introduction

The analysis in Earth laboratories of samples that could be returned from Mars is of extremely high interest to the international Mars exploration community.

IMEWG (the International Mars Exploration Working Group) is currently exploring options to involve the international community in the planning for returned sample science, including the analysis of the returned samples. The Mars 2020 sample-caching rover mission is an essential component of the Mars Sample Return campaign, so its existence constitutes a critical opportunity—MSR is more real now than it has ever been. The Mars 2020 samples, when returned, would provide the basis for performing a variety of Earth-based experiments including ones related to the search for the signs of life.

Proposed MSR Science Objectives

Seven objectives have been defined for MSR, traceable to published priorities established over more than two decades by Planetary Decadal Surveys in the USA and other international studies [e.g. 1, 2]. For each, their importance to science or engineering is described, critical measurements that would address the objectives are specified, and the kinds of samples that would be most likely to carry key information are identified.

1. Interpret in detail the primary geologic processes that formed and modified the ancient (pre-Amazonian) geologic record.

The objective seeks to investigate the geologic environment represented at a high-priority landing site (whichever site might be selected). All the sites are of ancient (Noachian or Hesperian) age. The intent is to provide definitive geologic context for samples and details that relate to past biologic processes. This objective is divided into sub-objectives that would apply at different landing sites.

1.1 Understand the essential attributes of a martian sedimentary system. The intent is to understand the preserved martian sedimentary record. Most important samples: A suite of sedimentary rocks that span the range of variation. Scientific importance: Basic inputs into the history of water, climate change, and the possibility of life.

1.2 Understand an ancient martian hydrothermal system through study of its mineralization products. The intent is to evaluate at least one potentially life-bearing 'habitable' environment via samples. Most important samples: A suite of rocks formed and/or altered by hydrothermal fluids. Scientific importance: A possibly habitable geochemical environment with high preservation potential.

1.3 Understand the rocks and minerals representative of a deep subsurface groundwater environment. The intent is to definitively evaluate the role of water in the subsurface. Most important samples: Suites of rocks/veins representing water/rock interaction in the subsurface. Scientific importance: May be the longest-lived habitable environments and key to the hydrologic cycle.

1.4 Understand ancient water/rock interactions at the martian surface, or more broadly, atmosphere/rock interactions, and how they have changed with time. The intent is to constrain the time-variable factors necessary to preserve records of microbial life. Most important samples: Regolith, paleosols, and evaporites. Scientific importance: Subaerial near-surface processes could support and preserve microbial life.

1.5 Understand the essential attributes of a martian igneous system. The intent is to provide definitive characterization of igneous rocks on Mars. Most important samples: Diverse suites of ancient igneous rocks. Scientific importance:

Thermochemical record of the planet and nature of the interior.

2. Assess and interpret the biological potential of Mars.

The objective seeks to inform our efforts to understand the nature and extent of martian habitability, the conditions and processes that supported or challenged life, the timescales, and how different environments might have influenced the preservation of biosignatures and created non-biological 'mimics'. This objective also has three sub-objectives.

2.1 Assess and characterize carbon, including possible organic and pre-biotic chemistry. Most important samples: All samples collected as part of Objective 1. Scientific importance: Any biologic molecular scaffolding on Mars would likely be carbon-based.

2.2 Assay for the presence of biosignatures of past life at sites that hosted habitable environments and could have preserved any biosignatures. Most important samples: All samples collected as part of Objective 1. Scientific importance: Provides the means of discovering ancient life.

2.3 Assess the possibility that any life forms detected are still alive, or were recently alive. Most important samples: All samples collected as part of Objective 1. Scientific importance: Planetary protection, and arguably the most important scientific discovery possible.

3. Determine the evolutionary timeline of Mars, including calibrating the crater chronology time scale.

This objective seeks to provide a radioisotope-based time scale for major events, including magmatic, tectonic, fluvial, and impact events, and the formation of major sedimentary deposits and geomorphological features. Most important samples: Ancient igneous rocks that bound critical stratigraphic intervals or correlate with crater-dated surfaces. Scientific importance: Quantification of martian geologic history.

4. Constrain the inventory of martian volatiles as a function of geologic time, and determine the ways in which these volatiles have interacted with Mars as a geologic system.

Comprising the atmosphere and hydrosphere, volatiles play major roles in martian geologic and possibly biologic evolution. The objective seeks to recognize and quantify these roles. Most important samples: Current atmospheric gas, ancient atmospheric gas trapped in older rocks, and minerals that equilibrated with the ancient atmosphere. Scientific importance: Key to understanding climate and environmental evolution.

5. Reconstruct the history of Mars as a planet, elucidating those processes that have affected the origin and modification of the crust, mantle and core.

The objective seeks to quantify processes that have shaped the planet's crust and underlying structure, including planetary differentiation, core segregation and state of the magnetic dynamo, and cratering. Most important samples: Igneous, potentially magnetized rocks (both igneous and sedimentary) and impact-generated samples. Scientific importance: Elucidates fundamental processes for comparative planetology.

6. Understand and quantify the potential martian environmental hazards to future human exploration.

The objective seeks to define and mitigate an array of health risks related to the martian environment associated with the potential future human exploration of Mars. Most important samples: Fine-grained dust and regolith samples. Scientific/engineering importance: Key input to planetary protection planning.

7. Evaluate the type and distribution of in-situ resources to support potential future Mars exploration.

The objective seeks to quantify the potential for obtaining martian resources, including use of martian materials as a source of water for human consumption, fuel production, building fabrication, and agriculture. Most important samples: Regolith. Scientific/engineering importance: Facilitating long-term human presence on Mars.

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Laboratory studies on thermal modification of mineral reflectance spectra in support of OSIRIS-Rex mission

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Abstract

We are investigating in laboratory spectral property of minerals in space simulated conditions supporting the interpretation of spectroscopic data collected with OVIRS [1] and OTES [2] instruments on board of sample return NASA OSIRIS-REx mission [3].
Specifically, we are investigating how different temperatures in lower pressure environment can affect spectral features in the wavelength range from visible to far infrared. This work is aimed in producing a spectroscopic database of different minerals dust with various grain size.

1. Introduction

Interpretation of data collected by OVIRS and OTES depends strongly on the optical properties of the material, grain sizes and temperature of regolith present on Bennu' surface [4]. Spectral library of silicates, carbonates, sulphates, oxides and organic molecules are commonly obtained at room temperature and ambient pressure. Up to now few studies were performed analysing the effects of different environments on spectroscopic features of pure minerals [5]. Nonetheless, decades ago it was questioned if temperature could affect spectral property of minerals. Furthermore, changes in the environmental pressure might cause changes in spectral features. Thus, it's important to acquire spectra in vacuum and at various temperatures for better simulating the environmental conditions found on Bennu. In this way, laboratory work on mineral spectral properties are fundamental in order to give a correct interpretation of data collect from the surface of Bennu during the orbital phase of OSIRIS-REx.

2. Experimental apparatus and samples

Our experimental apparatus at INAF-Astrophysical Observatory of Arcetri allows reflectance measurements in an extended spectral range from VIS to far IR and at different temperature from 64 K to 500 K with temperature stability ±0.1 K.
Interfacing an Oxford Instruments cryostat with a Bruker FT-IR spectrometer we are able, with the proper mirror geometry, to acquire reflectance spectra of different mineral dust samples. The cold finger of the cryostat with its sample holder hosting mineral dust is placed inside a micro tail equipped with different windows transparent at each spectral range analysed. Inside the micro tail high vacuum (with pressure $<10^{-5}$ mbar) is obtained with a turbo molecular pump.
Mineral samples are prepared in our laboratory from natural mineral with grain size ranging from 1 mm to less than 20 microns. Cleaning of organic contaminants is performed with optimal procedures well validated in previous work.

3. Results

The experimental work here presented will show spectroscopic changes on reflectance spectra of mineral dust in the VIS-NIR-MIR range at temperature 64 - 500 K in vacuum. Different mineral samples in different grain size were analysed to investigate the spectral modifications in simulated space environment. Our results show significant reversible changes in spectral features observed in reflectance. Changes affect different properties of spectra like peak position and band area with a similar trend for all the samples analysed (see Fig 1).

These results will be used for implementing the spectroscopic analysis of data returned from space missions of planetary surfaces.

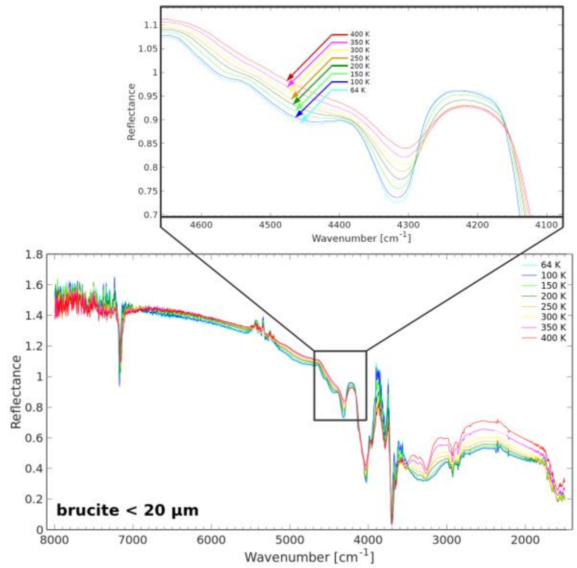

Figure 1 - Brucite reflectance spectra in medium infrared range at different temperature in vacuum.

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Mars Sample Return Engineering – A reference architecture for joint ESA-NASA studies and early mission concepts

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Abstract

1. Introduction

The analysis in Earth laboratories of samples that could be returned from Mars is of extremely high interest to the international Mars exploration community. The NASA Mars 2020 sample-caching rover mission is the first component of a potential Mars Sample Return (MSR) campaign, so its existence constitutes a critical opportunity. On April 26, 2018, NASA and ESA signed a Statement of Intent[1] to work together to formulate, by the end of 2019, a joint plan for the retrieval missions that has a sufficient level of technical and programmatic maturity that will lead to an international agreement between the two agencies in time to be submitted for approval to their respective authorities at the end of 2019. This abstract describes the reference engineering architecture of the MSR campaign, which forms the basis on which ESA and NASA will be performing joint studies over the next 18 months. Some concepts for the retrieval flight elements will also be presented based on the recent and on-going studies.

2. The MSR reference architecture

The architecture is based on three major flight elements and one ground element as depicted in Figure 1.

The Mars 2020 sample caching rover mission, which would be the first element of this campaign, is already in full flight development and is planned for launch in 2020 with a nominal 1.25 Mars-year mission to collect, analyze and cache samples for possible later retrieval.

The following two flights elements, not yet approved missions are the main subjects of the joint studies.

The Sample Retrieval Lander (SRL) element is assumed to be led by NASA and would carry the Mars Ascent Vehicle (MAV), as well as an ESA-provided Sample Fetch Rover (SFR) and Sample Transfer Arm (STA).

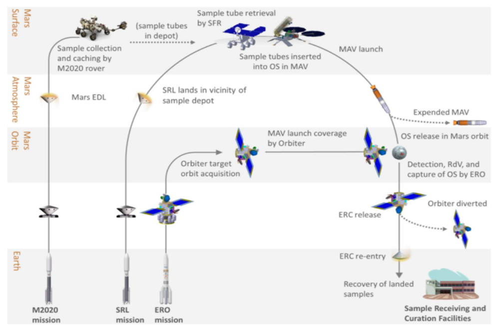

Figure 1: MSR reference architecture for joint ESA-NASA studies

The Earth Return Orbiter (ERO) element is assumed to be led by ESA and would carry a NASA-provided Sample Capture, Handling and Containment system as well as an Earth Entry Vehicle.

For the purposes of the joint studies, launch dates as early as 2026 for both the SRL and ERO missions are being considered, which could allow samples to be returned to Earth before the end of 2029.

The fourth element of MSR, based on the ground, would constitute all post-landing handling, sample receiving and curation activities, collectively known as Mars Returned Sample handling (MRSH).

A key driver for the MSR campaign will be the backward planetary protection requirements as it falls under the COSPAR Category V “Restricted Earth Return” categorization.

The information provided about possible Mars sample return architectures is for planning and discussion purposes only. NASA and ESA have made no official decision to implement Mars Sample Return.

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Mars sample return processing: X-Ray Computed Tomography of the Mars 2020 cache

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Introduction

The Mars 2020 rover mission will collect and cache samples from the martian surface for possible retrieval and subsequent return to Earth. If the samples are returned, that mission would present an opportunity to analyze returned Mars samples with geologic context on Mars. In addition, they may provide definitive information about the presence of organic compounds that could shed light on the existence of past or present life on Mars. Mars sample return (MSR) presents unique challenges for the processing and curation of samples [1]. Post-mission analyses will depend on the development of a set of reliable sample handling and analysis procedures that covers the full range of materials that may or may not contain evidence of past or present martian life.

MSR Curation Protocol- Initial scanning by XCT

As part of planning for the initial characterization and subsequent distribution to the scientific community, samples would be analyzed while still sealed in their containers with non-destructive, non-invasive techniques. Hanna et al. (2017) [2] suggest that X-ray Computed Tomography (XCT) may minimally alter samples for most subsequent techniques including organic analyses. The 2014 Report of the Workshop for Life Detection in Samples from Mars [3], published as an update to the 2001 Planetary Protection Draft Test Protocol, incorporates new findings and technological advances through community input. It also includes a comprehensive list of sample handling procedures and analytical measurements for returned Mars samples in the context of life detection and Planetary Protection. Assuming initial established protocols and procedures for controlled processing have been followed, the next step would be to address the methods for characterizing samples. At the top of the list is XCT analysis, would provide a three-dimensional whole sample reference, and would reveal physical heterogeneities at micron-level resolution including fractures, veins, porosity, lithologic and possibly mineralogical based structures. Higher dose X-rays would allow compositional details such as elemental distribution and mineralogy. Both reports [1,2] point out that the effects of increased radiation on the organics in samples would need to be evaluated. Because XCT systems can be configured for a variety of sources, detectors and geometric configurations, a detailed study of a variety of organic materials using multiple instruments is required for this evaluation.

Several recent studies show no alteration of organics [in meteorites] following exposure to synchrotron radiation [4], but work is needed to quantify the effects of laboratory XCT radiation on the types of organics that may be present in returned martian samples at fluences and energies that will allow in situ examination through the Mars 2020 cache tube. Our overall plan is to apply laboratory XCT radiation for a range of energies and fluences to a selection of organic compounds added to Mars analogue regolith material using compositions that reflect a Mars surface material composition. Results will be quantified with techniques appropriate (e.g. mass spectrometry) to better understand which classes of compounds are most susceptible and the subsequent products that may be produced. The materials will be tested using instruments at NASA Johnson Space Center and the Natural History Museum in London.

How Clean is Clean?

Organic contamination, as defined by the 2014 OCP [3] is “any substance that significantly interferes with our ability to detect the presence of martian organic compounds, or prevents our confidently determining that an organic compound is of martian and not terrestrial origin." Of equal concern is the possibility that any preliminary examination may alter what is expected to be a small organic signal that would be difficult to detect at even more energy intensive investigations. To ensure that preliminary interrogations would not diminish detection of a martian indigenous signal, or alter any known contaminants, we will conduct a set of experiments on Tier I compounds [3], which are compounds defined by the 2014 OCP as molecules that are potential contaminants, and likely to be most important to the science goals of the mission. Understanding the degree of alteration of these compounds during exposure to X-ray radiation is critically necessary to allow differentiation of contaminant versus native signal. It is a vital part of the framework for understanding signals that may be the result of alteration, allowing a degree of confidence in our conclusions that is necessary to meet the mission requirements.

Following X-ray exposure, we will define an alteration function based on a range of X-ray energies and intensities for nine isotopically labelled compounds from the Tier I [3] list: Adenine, Glycine, Glucose, Heptacosane, Napthalene, Palmitic acid, Pristane, Pyruvic acid, and Urea. Phased experiments will include pure analytes, analytes with known pure substrate in cache-like containers, and finally analytes with Mars analogue materials in cache-like containers.

Identifying a Mars Analogue:

Mars surface composition is well documented from 40 years of both orbital and landed missions. Most of Mars' surface is covered by a veneer of regolith that is sourced from a mix of martian and extraterrestrial infall materials [5]. Regolith will likely be a significant component of any returned samples collected at or near the surface. An Average Basalt Soil (ABS) reference is available for comparison, which is based on landed mission data [6]. When compared with ABS, analogues such as MMS and JSC Mars-1 are only a moderate compositional approximation. ABS, originally calculated by Taylor and McClennan (2009) [6] using Viking through MER-A and MER-B data, is recently updated by O'Connell-Cooper (2017) [6]. When compared against MSL's ChemMin data, the ABS shows that Mars regolith is likely a global unit with a primarily basaltic composition [6]. Comparing ABS against the average compositions of MMS and JSC Mars-1 along with shergottite EETA79001 Lithology A yields significant differences in Si, Fe, Al, and Mg oxides. As meteoritic infall is a known process impacting Mars surface [7], Allende, and average H and L chondrites were also reviewed. None of the materials alone are satisfactory analogues based on elemental comparison with ABS. Standard materials available from the USGS reference materials program, which included tholeiitic basalt from Iceland (BIR-1) and basalt from Hawaii (BHVO-2) were also considered. All show a range of variation from ABS, with the significant differences of low iron in the terrestrial rocks, and too little silica from meteorite infall materials. We are investigating the use of manufactured simulants [8] which would allow complete control over testing mission-specific analytical parameters and sample handling techniques for future missions.

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