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JAXA's Martian Moons eXplortaion, MMX

M. Fujimoto (1), **H. Miyamoto** (2) and K. Kuramoto (3) and the MMX Science Board members
(1) ISAS, JAXA, Japan, (2) University of Tokyo, Germany (hm@sys.t.u-tokyo.ac.jp), (3) Hokkaido University, Japan

Abstract

This paper describes the JAXA's Maritian Moon eXploration (MMX) mission that is under intensive study. The objective of the mission is to reveal the origin of the Martian moons, Phobos and Deimos. The goal beyond the objectives is to progress our understanding of the behavior of small bodies that delivered water from outside the snow line to the habitable zone of the solar system. The planned launch is in 2024 and various arrangements for international collaborations are moving in full-steam.

1. MMX Mission Objective and Goal

The origin of the Martian moons, Phobos and Deimos has been enigmatic. Two leading ideas are either that they are captured primordial asteroids or that they are formed by (not too gigantic) giant impacts. Detailed remote sensing observations by an orbiter may tell us the origin but analysis of returned samples enables us to step beyond revealing the origin. The goal beyond the objective is to progress our understanding of the behavior of small bodies that delivered water from outside the snow line to the habitable zone of the solar system.

The planets in the habitable zone of the solar system were born inside the snow line indicating that they were born dry. For the habitability to be switched on at all, water needs to be delivered from outside the snow line. Small bodies migrating across the boundary between the inner and the outer part of the early solar system are considered to play the role of delivery capsules of water (and organic compounds) from outside the snow line.

If the origin of Phobos is known to be captured primordial asteroid, it implies that Phobos had been one of the water delivery capsules but was captured during its journey from outside the snow line. Then detailed analysis of the samples allows us to study how the primordial materials, namely, water and organic compounds, are brought into the inner-part of the solar system. Sample analysis also allows us to unveil the migration history of the small body that behaved as a delivery capsule.

If the origin of Phobos turns out to be giant impact, samples will be composed of materials from ancient Mars and the impactor which can be a small bodey from outside the snow line. In a sense, Mars sample return is realized. Their analysis will reveal the impact size and allow us to evaluate how the initial evolution of Mars surface environment was affected by the violent satellite formation process that the small body triggered. Since the impact was likely to be of a decent scale, the nature of the impactor may be deciphered from analysis of samples that were less altered upon the impact than disabling the deciphering work.

Due to its close orbit to Mars, Phobos would have been showered by debris generated by impact events on the surface of Mars. That is, we may find samples from ancient Mars surface among samples to be collected from Phobos (even if its origin does not turn out to be giant impact). The Mars samples may span over a wide range in time and over a wide area on the surface, and may enable us to read-out the evolution history of Mars surface environment. This bonus aspect made us decide Phobos, not Deimos, as the target from which samples are returned.

2. MMX Mission Scenario and Science Instruments

The launch is planned to be in 2024 by an H-III launcher. Chemical propulsion will bring the spacecraft to Mars in one year. After Mars Oribit Insertion (MOI), orbital maneuver will put the spacecraft into a Quasi-Satellite Orbit (QSO) around Phobos. There is a variety of options for QSOs and the details are yet to be defined: The baseline QSO altitude is ~20km. From the QSOs, various remote sensing observations of Phobos will be performed, not only to characterize its surface but also to create maps based on which landing sites will be selected.

Sampling will be done as the spacecraft lands and stays on the surface for some hours. The sampling device, a corer situated on a tip of a robotic arm, is so designed that the minimum amount of the samples is 10g and that samples from more than 2cm below the surface are acquired.

On the exit leg out of the Mars system, multiple flybys of Deimos to make remote sensing observations are situated. Close-up observations of Deimos, and that with reference to the ground-truth results from Phobos, would enable us to give strong constraint to the idea for its origin. Returning samples from both Phobos and Deimos, unfortunately, does not fit within the envelope given to the ISAS space science program.

After spending three years in the Mars system, the spacecraft will be on its return cruise to Earth. The sample recovery will be in 2029. Sample analysis effort, mostly likely involving international participation via issuance of multiple AOs, will continue for some years.

The instruments selected to be onboard the MMX spacecraft are listed below:

[Sample science]

· Sampler and Re-entry Capsule: Acquisition of more than 10g Phobos genesis samples and Earth return from Mars orbit.

[Remote-sensing observations]

· Telescopic and wide angle multiband camera : To image geologic features and for spectroscopy of hydrated and non-hydrated silicate minerals and space weathering.

·Neutron and Gamma-ray spectrometer (NGRS): For measurements of silicate and volatile components.

· Near-Infrared spectrometer (NIRS): For spectroscopy of hydrated minerals and/or organic matter

· Light detection and ranging: To measure topographic features and to construct detailed shape model

[In-situ observations]

· Circum-Martian dust monitor: For Phobos space environment theme

· Ion mass spectral analyzer : To detect degassing from possible ice inside Phobos and for Phobos space environment theme

3. International Collaboration in MMX: Hot Topics as of April 2017

Phobos has been observed by previous missions but the existing data are not necessarily in a shape that allows smooth utilization by an independent party. In order to clear this hurdle, an effort supported by NASA that will enable easy access to the requested information is in progress. While the effort is not targeting especially at JAXA's MMX, MMX will be the first to gain benefit from the effort. The products will make an early international effort of studying a possible MMX landing site possible.

In late March 2017, NASA issued an AO for investigation utilizing NGRS to be onboard MMX. The selection process will be completed before the end of 2017. The selected PI will join the Science Board of MMX which has the highest authority in making science-oriented recommendation to the MMX Project Manager.

In April 2017, JAXA and CNES signed an Implementation Agreement (IA) related to MMX. The IA states that CNES continues to study the possibility of (1) provision of "MacrOmega" (NIRS), (2) participation in the study on flight dynamics in the close proximity of Phobos, and (3) provision of a small lander (~10kg) to be deployed from the MMX spacecraft to the Phobos surface.

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Planetary Sample Analysis Laboratory at DLR

J. Helbert (1), A. Maturilli (1) and J.P. de Vera (1)
(1) Institute for Planetary Research, DLR, Germany, (joern.helbert@dlr.de)

Abstract

Building on the available infrastructure and the long heritage DLR is planning to create a Planetary Sample Analysis laboratory (PSA), 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 goal of the first step is the preparation to receive 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.

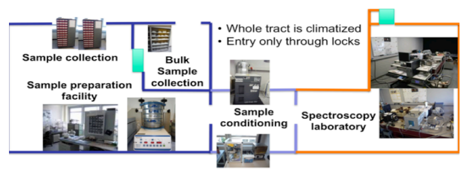
PSA will focus on spectroscopy on the microscopic scale and geochemical and geo-microbiological analysis methods to study elemental composition and isotopic ratios in addition to mineralogy to derive information on the formation and evolution of planetary surfaces, search for traces of organic materials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

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

2. Current facilities

The Planetary Spectroscopy Laboratory (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.

Figure 1: Current configuration of Planetary Spectroscopy Laboratory



In a climate-controlled environment PSL (Figure 1) 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

4. 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 PSA 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. DLR in Berlin is already operating similar several clean rooms for (optical) instrument development.

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 sample analysis laboratory is operational and ready for certification by mid of 2021. Analysis of first Hayabusa 2 samples will start by beginning to mid of 2022.

5. 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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COmet Nucleus Dust and Organics Return (CONDOR): a New Frontiers 4 Mission Proposal

M. Choukroun (1), **C. Raymond** (1), M. Wadhwa (2) for the CONDOR Science Team
(1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (mathieu.choukroun@jpl.nasa.gov), (2) Arizona State University, Tempe, AZ.

Abstract

CONDOR would collect and return a ≥ 50 g sample from the surface of 67P/Churyumov-Gerasimenko for detailed analysis in terrestrial laboratories. It would carry a simple payload comprising a narrow-angle camera and mm-wave radiometer to select a sampling site, and perform a gravity science investigation to survey changes of 67P since Rosetta. The proposed sampling system uses the BiBlade tool to acquire a sample down to 15 cm depth in a Touch-and-Go event. The Stardust-based sample return capsule is augmented with cooling and purge systems to maintain sample integrity during landing and until delivery to JSC's Astromaterials Curation Facility. Analysis of rock-forming minerals, organics, water and noble gases would probe the origin of these materials, and their evolution from the primordial molecular cloud to the 67P environment.

Introduction

Astronomical observations show that synthesis of both simple and complex organic molecules occurs in the interstellar medium, through various pathways including ice chemistry under ultraviolet irradiation. Links between these materials and Earth's prebiotic organic matter are unknown, and can only be probed on samples that contain pristine organic material. No well-preserved samples from the outer solar system exist to test ideas regarding solar system formation, and accretion of rocky planets with habitable surface environments. Current micro-analytical techniques have reached the point where the limiting factor in understanding the most primitive solar system materials is not instrument precision but instead is the lack of availability of less-processed, undamaged material that accreted in the outer solar system.

ESA's Rosetta mission makes 67P the best characterized comet to date. Water outgassed from the nucleus exhibits a high D/H ratio [1], suggesting a significant contribution of molecular cloud material to the isotopic budget. The surprising abundance of highly volatile species (e.g., O_2 and S) corroborates that 67P is a pristine sample of material accreted in the Kuiper Belt [2]. The surface of 67P is rich in organics, whose composition is partially understood from VIRTIS [3] and ROSINA data. Thus, 67P is an exceptional target for the first return of macroscopic, pristine cometary nucleus material to the Earth.

Overview of proposed mission

The CONDOR concept uses a Lockheed-Martin A2100 bus with a commercial solar-electric propulsion system to encounter and sample 67P at large heliocentric distances, when comet activity is minimal. The sample would be returned to Earth within 12.4 years, and curated at ≤ -80 °C.

Table 1: Proposed mission timeline

Event	Date (Sun distance, AU)
Launch	Jun. 16, 2024
67P Arrival	Apr. 25, 2029 (3.6)
Reconnaissance and Site Selection	Apr. 25, 2029 – Mar. 31, 2030 (3.6 – 5.1)
Sample acquisition	Mar. 31, 2030 – Sep. 9, 2030 (5.1 – 5.6)
67P Departure	Dec. 10, 2033 (3.3)
Earth Return	Nov. 8, 2036

Reconnaissance and Site Selection

We would follow 67P during its aphelion passage to survey changes since Rosetta and select a sampling site of high scientific value that is safe for the spacecraft. The proposed remote sensing payload (Figure 1) consists of a narrow-angle camera (NAC) from Malin Space Science Systems and a mm-wave radiometer (CONRAD) from JPL. The NAC is used to produce a global shape model with < 1 m resolution, as well as local digital elevation maps of candidate sampling sites at < 4 cm resolution. NAC narrow-band color imaging determines surface albedo and visible slope that is a proxy for ice. CONRAD is a three-channel radiometer that is sensitive to thermal properties, and enables CONDOR to see below the surface of 67P and find areas where primitive materials are accessible beneath a thin dust layer of < 10 cm thickness. The mass of the 67P nucleus is measured via X-band coherent Doppler radiometric tracking for 8 hrs/day, to determine total mass loss since 2016.

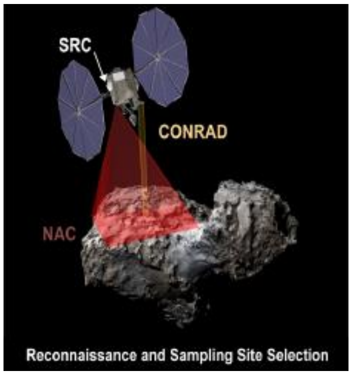

Figure 1: The site selection phase of CONDOR concept would last 340 days and consist primarily of mapping local topography with the NAC and thickness of surface dust cover with CONRAD.

Sample Acquisition

The BiBlade sampling tool [4], designed by JPL and constructed by Honeybee Robotics, would acquire up to 590 cc of comet material when filled to capacity (Figure 2). This is more than sufficient to return ≥ 50 g. It deposits the sample in a vault within the CONDOR sample return capsule (SRC), from Lockheed Martin, and releases a lid. The SRC contains two sample vaults, allowing return of up to two samples from 67P. Molecular sieves are integrated in the lids of the sample vaults to capture volatiles potentially released by the sample(s). Temperature inside the blades remains below -80°C.

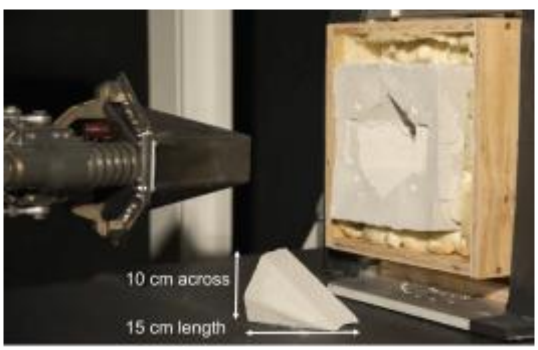

Figure 2: The BiBlade (TRL6) acquires a sample in materials up to 18 MPa cone penetration resistance, as hard as terrestrial permafrost.

Proposed Earth return and preliminary examination

After sample acquisition, CONDOR would stay at 67P until close enough to the Sun to allow departure and return to Earth. The SRC would be released on Nov. 8, 2036, and use an ammonia cooling system to maintain the capsule ≤ -20 °C until recovery. The SRC would also be purged with ^{40}Ar to prevent contamination from terrestrial atmosphere. After recovery, the sample(s) and hardware for contamination monitoring would be transported to JSC's Astromaterials Curation Facility at ≤ -20 °C, where < 25% of the sample is used for PE and > 75% of the sample is preserved for legacy at ≤ -80 °C.

The PE phase is projected to span the two-year period following sample recovery. A sample catalog would be produced within the first six months. Mineralogic and petrologic analyses inventory the materials to sub-micron scale. Elemental techniques determine the chemical composition of constituent materials. Analyses of the isotopic compositions of minerals, organic matter, and volatiles (H_2O and noble gases) determine their origin (presolar, formed in the outer/inner protoplanetary disk, mixed components) and evolution in the environment of 67P.

Acknowledgements

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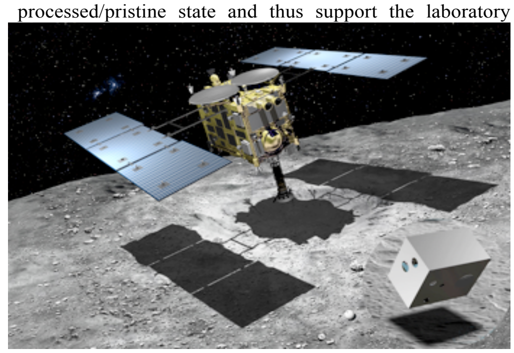
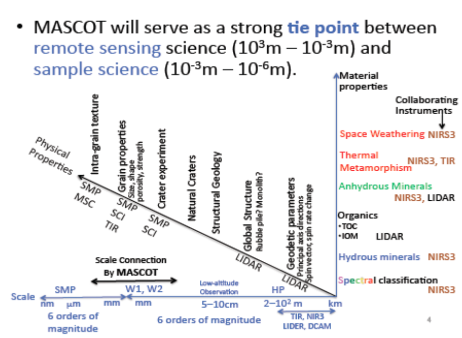
A MOBILE ASTEROID SURFACE SCOUT (MASCOT) for the HAYABUSA 2 MISSION to Ryugu

R. Jaumann (1,2), J.P. Bibring (3), K.H. Glassmeier (4), M. Grott (1), T.-M. Ho (5), S. Ulamec (6), N. Schmitz (1), H.-U. Auster (4), D. Herčik (4), J. Biele (6), C. Krause (6), H. Kuninaka (7), T. Okada (7), M. Yoshikawa (7), S. Watanabe (8), M. Fujimoto (7), C. Pilogret (3), V. Hamm (3), A. Koncz (1), T. Spohn (1)
(1) DLR, Inst. of Planetary Research, Berlin, Germany, ralf.jaumann@dlr.de; (2) Freie Univ. Berlin, Inst. of Geosciences, Berlin, Germany; (3) Univ. de Paris Sud-Orsay, IAS, Orsay, France; (4) Inst. of Geophysics, Univ. Braunschweig, Germany; (5) DLR, Inst. of Space Systems, Bremen, Germany; (6) DLR-MUSC, Linder Höhe, Cologne, Germany; (7) JSPEC/JAXA, Yoshinodai, Chuo, Sagamihara, Kanagawa, Japan; (8) Dep. of Earth and Planetary Sciences, Nagoya Univ. Furo-cho Chikusa-ku, Nagoya, Japan.

Introduction: MASCOT is part of JAXA's Hayabusa 2 asteroid sample return mission that has been launched to asteroid (162173) Ryugu (1,2,3) on Dec 3rd, 2014. It is scheduled to arrive at Ryugu in 2018, and return samples to Earth in 2020. The German Aerospace Center (DLR) developed the lander MASCOT with contributions from CNES (France) (2,3). Ryugu has been classified as a Cg-type (4), believed to be a primitive, volatile-rich remnant from the early solar system. Its visible geometric albedo is 0.07±0.01, its diameter 0.87±0.03 km (5). The thermal inertia indicates thick dust with a cm-sized, gravel-dominated surface layer (5,6). Ryugu shows a retrograde rotation with a period of 7.63±0.01h. Spectral observations indicate iron-bearing phyllosilicates (1) on parts of the surface, suggesting compositional heterogeneity. MASCOT will enable to in-situ map the asteroid's geomorphology, the intimate structure, texture and composition of the regolith (dust, soil and rocks), and its thermal, mechanical, and magnetic properties in order to provide ground truth for the orbiter remote measurements, support the selection of sampling sites, and provide context information for the returned samples (2,3). MASCOT comprises a payload of four scientific instruments: a camera, a radiometer, a magnetometer and a hyperspectral microscope (2,3,7,8). Characterizing the properties of asteroid regolith in-situ will deliver important ground truth for further understanding telescopic and orbital observations as well as samples of asteroids. MASCOT will descend and land on the asteroid and will change its position by hopping (3). This enables measurements during descent, at the touch-down positions, and during hopping. The first order scientific objectives for MASCOT are to investigate at least at one position: the geological context of the surface by descent imaging and far field in-situ imaging; the global magnetization by magnetic field measurements during descent and any local magnetization at the landing positions; the mineralogical composition and physical properties of the surface and near-surface material including minerals, organics and the detection of possible, near–surface ices; the surface thermal environment by measuring the asteroids surface temperature over the entire expected temperature range for a full day-night cycle; the regolith thermophysical properties by determining the surface emissivity and surface thermal inertia; the local morphology and in-situ structure and texture of the regolith including the rock size distribution and small-scale particle size distribution; the context of the observations performed by both, the instruments onboard the main spacecraft and the in situ measurements performed by MASCOT ('cooperative observations'). Provide documentation and context of the samples and correlate the local context of the in situ analysis with the remotely sensed global data; the body constitution on local and/or global scales and constrain surface and possibly sub-surface physical properties; the context of the sample collected and returned by the main spacecraft by qualifying its generic value and processed/pristine state and thus support the laboratory



Artist's conception of HY-2 during sampling, also showing MASCOT landed on the surface. CREDIT:JAXA/Akihiro Ikeshita.



analyses by indicating potential alteration during sampling, cruise, atmospheric entry and impact phases.

Measurement scenario: MASCOT enables measurements during descent, at the landing and up to two hopping positions, and during hopping. The first order scientific objectives for MASCOT is to investigate at least at one position: (1) the geological context of the surface by descent imaging and far field imaging in-situ; (2) the global magnetization by magnetic field measurements during descent and any local magnetization at the landing positions; (3) the mineralogical composition and physical properties of the surface and near-surface material including minerals, organics and detection of possible, near–surface ices; (4) the surface thermal environment by measuring the asteroids surface temperature over the entire expected temperature range for a full day-night cycle; (5) the regolith thermophysical properties by determining the surface emissivity and surface thermal inertia; (6) the local morphology and in-situ structure and texture of the regolith including the rock size distribution and small-scale particle size distribution; (7) the context of the observations performed by the instruments onboard the main spacecraft and the in situ measurements performed by MASCOT ('cooperative observations') and provide documentation and context of the samples and correlate the local context of the in situ analysis into the remotely sensed global context; (8) the body constitution on local and/or global scales and constrain surface and possibly sub-surface physical properties; (9) the context of the sample collected and returned by the main spacecraft by qualifying its generic value and processed/pristine state and thus support the laboratory analysis by indicating potential alteration during cruise, atmospheric entry and impact phases. In addition to the main science objectives further science measurement can be performed by the lander's engineering sensors that are supposed to monitor the housekeeping and/or provide the right measuring orientation/position of MASCOT and by the scientific payload based on their given favourable observing conditions within the lander's nominal operation mode ('opportunity science').

Instruments: The camera (2) will provide ground truth for the orbital measurements of the Hayabusa-2 orbiter instruments and the in-situ MASCOT sensor suite and to provide context of the undisturbed sampling sites. This is achieved by contributing to the determination of the structural, textural and compositional characteristics of the surface layer on scale lengths ranging from tens of meters to a fraction of a millimeter, by means of multi-color imaging of the asteroid's surface.

The camera will operate both as descent and in-situ imager (both during day and night phases). Imaging will start shortly after the separation from the Hayabusa-2 mother S/C and images will be acquired until touchdown. The images will close the resolution gap between orbital and in situ imaging and allow for determining the landing site within the orbiter camera dataset. After touchdown, the camera will acquire wide angle images of the asteroid's surface. Multispectral imaging during dark phases is achieved through an illumination device consisting of four arrays of monochromatic light emitting diodes working in 4 spectral bands that allow classifying and mapping compositional heterogeneity of the asteroid's surface by the means of color ratios Image series at different sun angles over the course of a day will also contribute to the physical characterization of the asteroid surface properties by photometric analysis. The radiometer is a multispectral instrument which will measure the radiative flux emitted from the asteroid's surface using thermopile sensors. Six individual filters will be employed to measure the flux in the wavelength bands between 5.5-7, 8-9.5, 9.5-11.5, 13.5-15.5, 8-14, and 5-100 µm in order to determine the asteroid's thermal inertia and to support mineralogical characterization. The magnetometer will measure the global magnetic field during descent and hopping phases either indicating a global magnetization of the asteroid or induction effects due to time-varying external magnetic fields. Furthermore, magnetic field vectors at the individual landing and hopping locations will be determined in order to characterize the magnetic properties of surface materials that will allow understanding the magnetic evolution of asteroidal bodies. The hyperspectral microscope will surface samples a few mm2 in size, with a resolution of 20 µm, as to their structure and composition. On each pixel, the spectrum is acquired from 0.9 to 3.5 µm, in more than 300 contiguous spectral channels. The spectral range and resolution have been chosen so as to enable to retrieve the composition of the major and minor constituents present in each image element: most minerals, both pristine and altered, have diagnostic signatures in this domain, as well as most frosts and ices, and noticeably, organics. Thus a microscopic determination of the asteroidal surface composition is provided down to its grain scale, offering key clues to decipher its origin and evolution. The external window of the hyperspectral microscope is in direct contact with surface material. An illumination system, based on an acousto-optic tunable filter, provides a monochromatic enlightening of the sample through the window, and an image is acquired on a 2D infrared cooled detector.

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Starting a European Space Agency Sample Analogue Collection (ESA²C) and Curation Facility for Exploration Missions.

C. L. Smith[1], M.S. Rumsey[1], K. Manick[1], S-J. Gill[1], C. Mavris[1], H. Schroeven-Deceuninck[2] and L. Duvet[2]

[1]Department of Earth Sciences, Natural History Museum, London, SW7 5BD, UK c.l.smith@nhm.ac.uk. [2]ESA ECSAT, Fermi Avenue, Harwell Campus, Didcot, Oxfordshire, OX11 0XD, UK.

1. Introduction

Since 2014, the Natural History Museum (NHM) has been the prime contractor to the European Space Agency (ESA) for defining and initiating the development of a Sample Analogue Collection and supporting Curation Facility in support of the Robotic Exploration mission preparation programme. The ESA Sample Analogue Collection (ESA²C) will support the ongoing or future technology development activities that are required for human and robotic exploration of Mars, Phobos, Deimos, C-Type Asteroids and the Moon. The long-term goal of this work is to produce a useful and useable resource for engineers and scientists developing technologies for ESA missions.

2. Analogue Requirements Definition

The complex mission architectures and diverse target bodies of interest means that a variety of different analogue materials are required to test all systems that come into contact with the target body, whether these be part of the spacecraft system, such as landing and/or roving systems (e.g. wheels), sample collection systems (e.g. drills or scoops) or scientific payload. The analogue materials must replicate as far as possible the expected 'geological' environment of the target body in terms of both physical/mechanical properties and chemical/mineralogical properties. Defining a set of well-characterised analogue materials, with both appropriate geotechnical and chemical properties, which could potentially be used as part of an 'end-to-end' methodological approach for testing, evaluation and verification of requirements during mission development would be highly advantageous. Figure 1 shows a simple flow chart identifying the main mission architecture elements that are relevant to any exploration mission and identifying the broad categories of analogues required for testing and verifying different engineering and payload technologies.

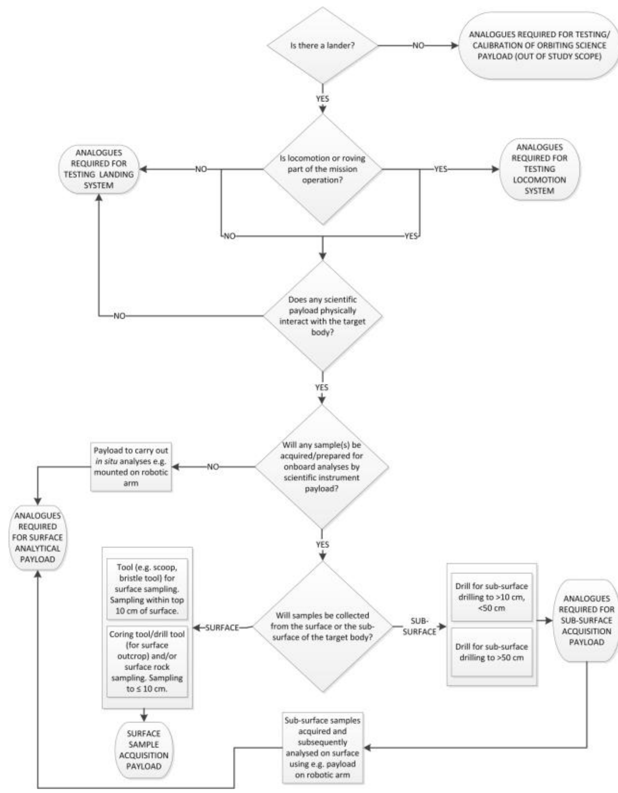

Figure 1. Flow diagram showing an overview of mission architectures/operations applicable to Solar System robotic exploration missions and where analogue samples would be applicable for technology testing.

3. Analogues Samples Definition

In addition to ensuring that the samples as accurately as possible represent the physical and chemical properties of the target bodies of interest, it is important to select materials that can be readily obtained both now and in the future, in enough volume that will ensure a sustainable collection. As is the case for the existing NASA lunar and martian analogues (JSC-1A and JSC-Mars-1A) [1] we have selected samples that are available from commercial suppliers to mitigate the risk of materials becoming unavailable and to ensure large quantities can be sourced if necessary. Additionally, as our chosen suppliers provide materials to a number of industries e.g. construction, large-scale civil engineering projects, we are confident in the quality control procedures in operation during material production, which should allow for good reproducibility in sample properties over time. Samples selected include a variety of aggregates from the olivine-rich basalts from the Upper Lava Formation of the Paleogene Antrim Lava Group of Northern Ireland and clay samples from Cyprus, Spain and Senegal. Table 1 shows a summary of the materials selected as being suitable for inclusion in the ESA^{2}C.

Table 1. Summary of samples forming the initial ESA2C

Analogue Material Type		Physical Description	Relevant Target Body	Mineralogy
Basalt	Basalt Rock	150-200 mm gabion stone	Mars, Moon	Feldspar ($Ab_{35-46}Or_{1-2}An_{52-64}$) Olivine ($Fo_{54-60}$) Pyroxene ($En_{36-39}Wo_{44-46}Fs_{16-18}$) Ilmenite
	Basalt Aggregate	19 mm, 10 mm, 6 mm and 3 mm and down (dust)	Mars, Moon	
Clay Granules	Sepiolite	Granular materials up to ~10 mm in size	Mars, Mars' moons, C-type asteroids	Palygorskite-sepiolite group with smectite component (>95%). Minor calcite, dolomite, quartz, mica (<5%)
	Attapulgite			Palygorskite-sepiolite group with smectite component (>90%). Minor Ca plagioclase, calcite, dolomite (<10%)
	KM Granules			Smectite group minerals (>90%). Minor quartz, calcite, mica, chlorite (kaolinite?) (<10%).
Clay powders	KMA	Very fine grained with 75 % <75 µm size	Mars, Mars' moons, C-type asteroids	Smectite-group minerals (>95%). Minor quartz, feldspar, calcite, magnetite (<5%)
	KM2			Smectite group minerals (>95%). Minor quartz, calcite, dolomite feldspar, magnetite
	KMSR			Smectite group minerals (>90%). Minor quartz, calcite, mica, feldspar, chlorite (<10%).

4. Analogue Characterisation

During 2016 we carried out a detailed characterisation of the analogue samples' physical and chemical properties [2,3]:

Chemical properties

• Whole-rock chemistry – major, minor and trace element analyses by ICP-AES and ICP-MS.

• Mineralogy – analytical SEM, EPMA and XRD (whole-rock).

Physical properties

• Grain size and shape – sieving and visual inspection, X-ray micro-CT.

• Bulk density and porosity – mass-volume measurement and helium pycnometry, X-ray micro-CT.

• Shear strength (aggregate and powder samples) – shear box apparatus.

• Compressive and tensile strength – UCS testing and Brazilian indirect tensile method.

5. Sample Analogue Curation Facility

This unique venture will build on the Robotic Exploration mission preparation programme by establishing methodologies and protocols/procedures for curating the ESA^{2}C, as well as defining and validating the distribution mechanisms and information exchange protocols for the analogue materials. Underpinning the work will be the development of the ESA^{2}C database that will be undertaken by the NHM in the coming year. Samples will be available to suitable qualified PIs and we welcome requests for information on the samples we have already acquired and characterized.

As part of ongoing work, additional samples to those shown in Table 1 were acquired for the ESA^{2}C. Anorthosite blocks were acquired from a Norwegian quarry and basaltic sand/gravel and basaltic/hyaloclastite blocks were collected from the Askja Region in Iceland. Additionally, sample mixtures will be made up using the characterised clays and basalts for varying grain sizes and clay:basalt ratios to better replicate the Phobos/Deimos/C-Type Asteroids and Martian regoliths. We will continue to seek sources of new materials for potential acquisition and subsequent characterization to enhance the initial collection. A critical part of our work is to actively collaborate with our colleagues in the space mission engineering and planetary sciences communities to ensure that the ESA^{2}C is a relevant and practical resource for technology development.

Acknowledgements

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Phobos sample return mission: Prediction of Phobos composition from a giant impact and implications for the MMX/JAXA mission

P. Rosenblatt (1), R. Hyodo (2), J.-P. Bibring (3), H. Genda (2), Charnoz S. (4,5) and Pignatale F.C. (4)
(1) Royal Observatory of Belgium, Brussels, Belgium (rosenb@oma.be / Fax: +32 2 374 98 22), (2) Earth and Life Science Institute (TIT), Tokyo, Japan, (3) Institut d'Astrophysique Spatiale, Paris, France, (4) Institut de Physique du Globe, Paris, France, (5) Université Paris Diderot, Paris, France.

Abstract

We present computations of possible mineralogical composition of material formed in a post-impact debris disk around Mars. The goal of this study is to predict potential minerals condensed in a circum-Martian disk from which Phobos and Deimos might be formed. The results of this study could be used as guidelines for both the remote sensing of Phobos surface and the analyses of samples from Phobos that will be returned to Earth by the JAXA Mars Moon eXplorer (MMX) mission, due to launch in 2024.

1. Introduction

The origin of the Martian moons is still strongly debated. Are they captured asteroids -owing to their spectra reminding those of D-type asteroids [1] - or did they form after a giant impact in the way our own Moon formed [2]? In order to answer this important question with respect to the early dynamics of the solar system, the JAXA has recently decided to send a spacecraft (MMX, Mars Moons Explorer) that should return Phobos samples on Earth in 2027 or 2029. One of the prime objectives of MMX is to decipher the origin of Phobos, which is in great part recorded in its composition. The payload of the mission is thus focused on the characterization of the surface composition of Phobos with a Gamma-spectrometer for elemental composition and an Infra-red spectrometer for mineralogical composition. They will be complemented by in-depth analyses of returned samples, including the determination of the isotopic composition. All these observations will be key for testing and constraining the scenario of origin. Is the composition of Phobos similar to those of asteroids? Could the composition of Phobos be accounted for by condensation of material in a circum-Mars accretion disk? What is the age of Phobos material? In addition to the returned samples, the instruments onboard MMX are well suited for answering those questions. The near-IR spectro-imager instrument, MacrOmega (CNES) onboard MMX, will provide us with images and spectra at high spatial resolution in the wavelength band of 0.5-3.8 microns that will allow the identification of the igneous and altered minerals as well as of potential volatile phases (aqueous and carbonaceous) at the surface of Phobos. It will allow for characterizing the material Phobos is made of and to compare it with Mars material (a mixture of both Mars and impactor material are indeed expected in the accretion disk [2,3]). In addition to mineralogy, the gamma spectrometer aboard MMX will allow to measure elementary atomic composition. Due to the high temperature during the impact event some devolatilisation of the most abundant volatile species (like Zn, or K) may indeed be expected.

We present here new high-resolution simulations of the formation of Phobos in a giant collision scenario. By computing the temperature and pressure of the post-impact debris disk made of a mix of Mars and impactor material [3], we compute the condensation sequence of the first minerals in the condition of the Phobos accretion. It provides a new theoritical framework to interpret the future observations of the MMx mission.

2. The condensation sequence in the circum-Mars debris disk

We perform numerical simulations of the disk-formation just after the giant collision using Smooth Particles Hydrodynamics (SPH) code. We assume this collision has formed the Borealis basin giving constraints on the energy of the impact, i.e. a less energetic impact than in the case of the formation of the Earth's Moon [3]. We add equation of state allowing for computation of temperature and pressure increase in the disk due to the energy released during the collision [3]. We also track for the particles originating from Mars and from the impactor in order to get the repartition of the two kind of material expected to be present on the circum-Martian disk. Then, using temperature, pressure variations in the disk (i.e. tracking cooling of the disk) as well as initial material repartition (Mars vs impactor), we compute the condensation sequences in order to get the series of minerals that can be formed in this circum-Martian disk. Starting from different initial compositions of the impactor (from carbonaceous to silicates), we, thus, assume thermodynamic equilibrium and use the Gibbs free energy minimisation technique [4] to solve for the stable phases. The resulting mineralogies are taken as proxies for the building block of Phobos. Thermodynamic equilibrium has been extensively used in the past for the study of the chemistry in several astrophysical environments from the Solar Nebula and meteorites [5,6,7] to stars' dusty envelopes [8] and exoplanets' composition [9], providing a reliable and powerful tool.

3. Summary and Conclusions

The MMx mission will be a milestone in the exploration of Mars and for constraining the formation processes of satellites in the inner Solar System. The Martian case indeed constitutes a unique witness of the dynamical processes, which have driven the early evolution of the solar system, responsible for the diversity of planetary worlds revealed by the space exploration of the solar system. The composition of Phobos is likely to preserve key records of its origin, through its mineralogical, elemental and isotopic composition. Instruments aboard the MMX mission will allow to characterize this composition and so to provide strong constraints on the origin of the Martian moons, currently considered through two 'end members' scenarios: Is Phobos of primitive composition like for asteroids or is Phobos composed of some material (Mars and impactor material mixture) expected in the giant collision scenario?

This paper presents new computations of the sequence of minerals one might expect from a Phobos formation triggered by a giant impact on Mars.

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Basic requirements for packaging and transporting returned extraterrestrial samples from landing site to curation facility

A. Longobardo (1), F. Dirri (1), E. Palomba (1), L. Berthoud (2), J. Holt (3), J. Bridges (3), C. Smith (4), S. Russell (4) and the EURO-CARES Consortium
(1) INAF-IAPS, via Fosso del Cavaliere 100, 00133 Rome, Italy (andrea.longobardo@iaps.inaf.it); (2) Thales-Alenia Space UK, Bristol, UK; (3) University of Leicester, Leicester, UK; (4) National History Museum, London, UK

Abstract

In perspective of a possible European sample return mission, we summarize basic requirements of the transportation box, which should transport returned extraterrestrial samples from landing site to curation facility.

1. Introduction

EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space) is a Horizon2020 research program aimed at creating a roadmap for the implementation of a European Extra-terrestrial Sample Curation Facility. This facility would receive returned samples from sample return missions (SRM) to asteroids, Mars or Moon.
The returned extra-terrestrial samples must be kept clean in order to minimize the risk of forward contamination (i.e. from terrestrial environment and from the container itself transporting them).
This work is aimed at identifying the requirements of the transportation box which should contain the Sample Return Capsule (SRC), which in turn contains the extra-terrestrial samples returned to Earth. After packaging of SRC in the box, the latter is transported from landing site to curation facility, where it will be opened and the samples will be recovered and analyzed.
Transportation box design differs depending on the mission scenario, i.e. restricted (samples having significant role to understand processes of chemical evolution and/or origin of life and hence required to be preserved in special conditions) or unrestricted.

2. Regulations

Packaging and transport of samples must guarantee safety of people performing these operations and hence must be done according to the World Health Organization (WHO) rules [1]. WHO discerns three types of samples: Category A, i.e. potentially causing permanent or fatal diseases, Category B, i.e. potentially causing minor diseases, and not hazardous. Restricted samples, e.g. from Mars and Europa, should be treated as “Category A” samples (unless they are sterilized), since it is not known if they could contain simple forms of life which could cause disease in humans. Lunar and asteroid samples are instead not hazardous.
A triple packaging must be applied to Category A samples: 1) primary receptacle; 2) durable, leak-proof secondary package (plastic material); 3) rigid, cushioned outer layer. An additional layer should be considered if samples need to be preserved in special conditions or to be monitored during transport.
Even if not hazardous, lunar and asteroid samples however need a package aimed at avoiding Earth contamination.

3. General requirements

The primary receptacle coincides with the SRC, hence its design depends on the mission requirements and is beyond the scope of this work.
In order to avoid fluid leakage (e.g. phase transition in restricted samples), SRC should be surrounded by absorbent material. Polypropylene is the most commonly used and is suitable for transportation boxes, since is a low-density material and outgasses only at very high temperatures.
The plastic material of the secondary package must have a low outgassing rate (i.e. $<10^{-7}$ Torr/s). A trade-off analysis was performed for materials having this requirement, i.e. Polyurethane, Teflon, Neoflon and Kalrez [2]. Polyurethane and Kalrez were discarded because of their high permeability and cost, respectively, and therefore Teflon and Neoflon would be the best choice.

The outer package must be rigid and resistant to breakage, hence a trade-off analysis was performed on metallic alloys, and based on Young's modulus, outgassing rate, density (lighter materials should be preferred), thermal conductivity (samples may need to be thermally insulated) and cost. Stainless steel is by far the lowest outgassing material and the easiest to clean, has a low thermal conductivity and is the cheapest material. The only weakness is its high density, and this may be an issue for packaging of large SRC. In that case, aluminium alloy may be preferred.
The outer has to be filled with an inert atmosphere, in order to inhibit oxidation within the sample. Argon is more inert than nitrogen, but however we suggest the latter, due to its wider availability and lower cost.
The overpack should be required when the box environment needs to be controlled in stronger detail, e.g. real-time contamination monitoring inside the outer and inner packages. This is the case for restricted samples, which should be preserved with special care. ISO containers could be used to this end. Contamination of the environment inside the box can be monitored by different instruments, which should be selected on the basis of mission requirements (i.e. a GCMS should be preferred if a high sensitivity is required, whereas QCM's are much less mass demanding, e.g. [3]).

4. Basic design

Basing on the requirements identified above, the transportation box should be based on a layered configuration: i) primary receptacle, coinciding with SRC and possibly surrounded by polypropylene (restricted case); ii) Teflon/Neoflon secondary package (optional for unrestricted samples); iii) metallic outer package, filled with nitrogen; iv) ISO container (overpack) with an internal laboratory for environment control, required only in the restricted case. Schematic views of transportation boxes in unrestricted and restricted case are shown in Figures 1 and 2, respectively.

5. Transport

There are no mass limitations for box transport by ground or ship. The weakness of these solutions is the much larger journey duration. Any aircraft might be used for transporting unrestricted samples. Only cargo aircraft may be used for transporting restricted samples, unless the total sample mass is lower than 50 grams [1]. However, the transport of a box filled with pure nitrogen is allowed only on military aircrafts, and hence this solution might be preferred.
Moreover, the box must be properly labelled and marked, according to [1]. It should be taken into account to add additional marking in the case of non-nominal scenario (e.g. broken or damaged SRC).

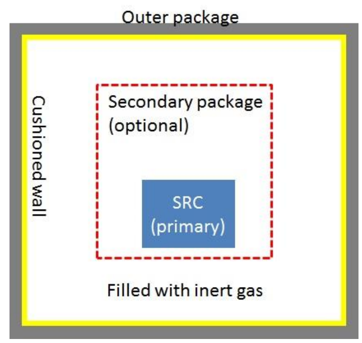

Figure 1. Schematic view of transportation box structure for unrestricted missions.

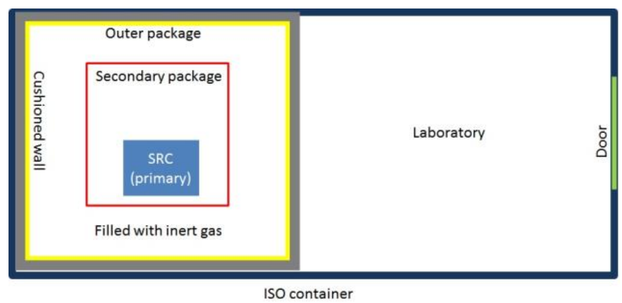

Figure 2. Schematic view of transportation box structure for restricted missions.

Acknowledgements

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Basic design of sample container for transport of extraterrestrial samples

F. Dirri (1), A. Longobardo (1), E. Palomba (1), A. Hutzler (2), L. Ferrière (2) and the EURO-CARES Consortium

(1) Institute for Space Astrophysics and Planetology (IAPS-INAF), Via del Fosso del Cavaliere 100, 00133, Rome, Italy (fabrizio.dirri@iaps.inaf.it), (2) Natural History Museum, Burgring 7, A-1010 Vienna, Austria

Abstract

The aim of this work is to provide, in the framework of the EURO-CARES (European Curation of Astromaterials Returned from Exploration of Space) project [1], a technical overview based on the sample container used in previous sample return missions (e.g., Hayabusa1, Stardust, etc.) and to define a basic design of a sample container aimed at transporting the extraterrestrial returned samples within a Sample Curation Facility (SCF) or from a SCF to another laboratory (and vice versa). The sample container structure and the transportation criticalities (such as contamination and mechanical stress) are discussed in detail in each scenario.

1. Introduction and guidelines

In order to ensure safe storage conditions and to avoid terrestrial contamination of extraterrestrial samples returned from future missions, it is necessary to define requirements for sample containers and their transport, inside an SCF and from an SCF to other laboratories (and vice versa). Based on the experience of previous sample return missions, we defined a basic design of a sample container which can be used for the storage and transportation of extraterrestrial samples. The sample container design and optional components depends on mission scenario: restricted, i.e. samples having a significant role to understand the origin of life (e.g. from Mars and Europa); unrestricted, i.e. samples from undifferentiated, metamorphosed asteroids and from the Moon. Samples from Mars and Europa should be treated as Category "A" [2], i.e. potentially causing fatal diseases whereas Lunar and asteroid samples should be treated as not hazardous sample.

Different sample containers have been already produced in the framework of previous missions to guarantee the integrity of returned samples by avoiding the external contamination [3,4]. For example, in the case of Hayabusa and Hayabusa2 missions (Fig. 1), the containers in which the returned samples were packaged, mainly consisted of an outer lid equipped with latches, an inner lid, a frame for latches, a non-explosive actuator, and a sample catcher. The sample container is sealed with double Viton O-rings and maintained in an ultra pure nitrogen atmosphere [5,6].

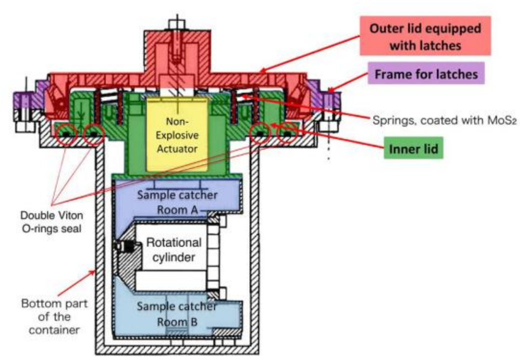

Figure 1. Schematic view of a cross-section of the sample container of Hayabusa and Hayabusa2.

Basically, in order to transfer extraterrestrial samples inside an SCF and from an SCF to laboratories, the following sample container requirements have to be met: 1) samples should be kept under the same storage conditions of temperature, pressure, cleanliness, and humidity; 2) minimization of forward contamination (i.e., from terrestrial environment); 3) in case of restricted samples, it should prevent backward contamination (i.e., no release of potential biologically active contamination into the ambient environment is accepted).

2. Transportation scenarios and sample container basic design

After the landing of a sample return mission, three types of transportation are foreseen to move samples: 1) from landing site to SCF [7]; 2) within the SCF; 3) from SCF to other laboratories (and vice versa). In the 2nd and 3rd scenarios (unrestricted case) the sample container should be composed of: 1) a sample collector (Fig. 2, left), which should include (single) samples, 2) a metallic collector protection (that should include a window with a teflon substrate), which aimed at insulating the samples and reduce their motion, 3) a cover with latch mechanism and seals (which may be in Viton, due to its properties, especially its low outgassing rate). Other optional component, i.e., a pressure system (to keep the samples under an inert gas atmosphere) and a plastic material encapsulation should also be considered for restricted samples (e.g., from Mars).

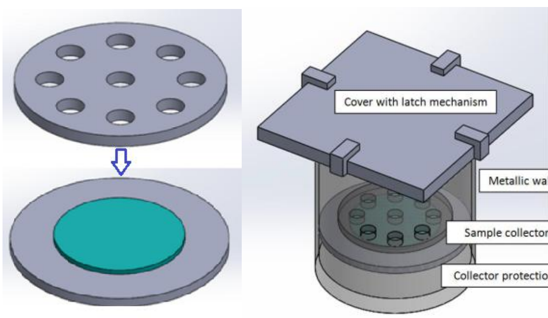

Figure 2. *Left:* Sample collector ("racket" model). *Right:* Basic design of a sample container (unrestricted case).

Otherwise, when the sample is transported from SCF to other laboratories (and vice versa), the samples should be placed in a double or triple package: the sample container (Fig. 2, *right*) will be the internal layer while the other two additional layers will aim at protecting the sample(s) from forward contamination and from vibrations/shocks during transportation [5].
The best material to be used for the sample containers mechanical structure should be stainless steel due to the lower outgassing rate (e.g., two orders of magnitude less than Titanium) and the cost (e.g., 10 times less than Titanium). On the other hand, the most indicated material for the plastic bag is Neoflon (KEL-F) due to its lower permeability to water, nitrogen, and CO_2 [8]. Otherwise, for covering the internal walls of the sample container, Teflon [9] would be preferred since it is cheaper (three times less than Neoflon KEL-F).

3. Conclusions

Guidelines, requirements, basic design, and materials which should be used for a sample container were determined for transportation of extraterrestrial samples inside the SCF or from the SCF to other laboratories (and vice versa). In particular, two different configurations have been defined, i.e., the sample container (sample collector, collector protection, and metallic walls) and the triple packaging (sample container, plastic bag, metallic box) for the transportation between laboratories (unrestricted case). In the latter case, additional precaution has been identified to prevent the risk of fluid leakage and to minimize the shocks.
The criticalities about the material have been defined on the basis of outgassing rates (which should be very low), cost and permeability to water, nitrogen, and CO_2. For restricted samples, slightly different requirements have to be take into account for the two sample container configuration.

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Spectral mapping in the OSIRIS-REx mission

Beth Clark (1) and the OSIRIS-Rex Team

(1) Ithaca College, New York, NY, USA

Abstract

The presentation will introduce science goals of the OSIRIS-REx mission and will focus on the spectral mapping components, namely the visualization of spectral measurements on the 3D map standard of the mission.