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MarcoPolo-R ESA Sample Return Mission to 2008EV5 (A Potentially Hazardous Asteroid)

Barucci, M.A. (1), Michel, P. (2), Böhnhardt, H.(3), Brucato, J.R.(4), Dotto, E.(5), Ehrenfreund, P.(6), Franchi, I.A.(7), Green, S.F.(7), Lara, L.-M.(8), Marty, B.(9), Koschny, D.(10), Agnolon, D.(10), Chalex R.(10), Martin, P.(11), and Romstedt, J.(10)

(1) LESIA, Paris Observatory, 5, place Jules Janssen , 92195 Meudon Cedex, France, antonella.barucci@obspm.fr
(2) University of Nice-Sophia Antipolis, CNRS, Côte d'Azur Observatory, Boulevard de l'Observatoire, B.P. 4229, 06304 Nice Cedex 4, France, michelp@oca.eu
(3) Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany, boehnhardt@mps.mpg.de
(4) INAF – Osservatorio Astrofisico di Arcetri, Firenze, Italy, jbrucato@arcetri.astro.it
(5) INAF – Osservatorio di Roma, Monte Porzio Catone, Italy, dotto@mporzio.astro.it
(6) University of Leiden, Leiden, The Netherlands, p.ehrenfreund@chem.leidenuniv.nl
(7) CEPSAR – The Open University, Milton Keynes, UK, i.a.franchi@open.ac.uk; S.F.Green@open.ac.uk
(8) Instituto de Astrofisca de Andalucia, CSIC, Granada, Spain, lara@iaa.es
(9) CRPG/CNRS, Nancy, France, bmarty@crpg.cnrs-nancy.fr
(10) ESA/ESTEC, Noordwijk, The Netherlands, Detlef.Koschny@esa.int; David.Agnolon@esa.int; jromsted@rssd.esa.int
(11) ESA/ESAC, Madrid, Spain, patrick.martin@sciops.esa.int

Abstract

MarcoPolo-R is a sample return mission to a primitive Near-Earth Asteroid (NEA) selected in 2011 for the Assessment Study Phase of M3-class missions in the framework of ESA's Cosmic Vision (CV) 2015-2025 programme. The phase A study started at the end of 2012 and will proceed throughout 2013. The final selection by ESA will occur in February 2014. MarcoPolo-R is a European-led mission with a possible contribution from other agencies. MarcoPolo-R will rendez-vous with the primitive NEA 2008 EV5. Before returning a unique sample to Earth, the asteroid will be scientifically characterized at multiple scales. MarcoPolo-R will provide detailed knowledge of the physical and compositional properties of a member of the population of Potentially Hazardous Asteroids (PHA), which is an important contribution to mitigation studies.

Keywords: *primitive asteroid, hazardous asteroid, characterization, space mission*

1. Introduction

Small bodies of our Solar System can retain evidence of the primordial solar nebula and provide a record of early Solar System processes that shaped their evolution [1]. They may also contain pre-solar material as well as complex organic molecules that may have contributed to life's precursor material [2,3,4]. For these reasons, small Solar System bodies such as asteroids and comets have been the target of interest of space missions for over three decades. The study of the physical properties of NEAs is also fundamental to assess the potential hazard imposed by a NEA impact on our planet. The complex mixture of materials that form an asteroid regolith can only be revealed with the necessary precision and sensitivity using instrumentation available in laboratories on Earth. In particular the precise chemical and isotopic composition of individual compounds is vital to determine the evidence of stellar, interstellar medium, pre-solar nebula and parent body processes that are retained in primitive asteroidal material. Therefore it is no surprise that sample return missions are considered a priority by a number of leading space agencies. Abundant within the inner Solar System, small bodies are thought to have been, through impacts with Earth, the principal contributors of water and organic material essential to create life on Earth [5,6]. Small bodies offer us a unique window to investigate both the formation of planets and the origin of life. Moreover, in our contemporary epoch, such small bodies also represent both a potentially rich resource for future space exploration and a threat to the very existence of humankind.

Near-Earth Asteroids are a continuously replenished population of small bodies with orbits that come close to or cross the Earth's orbit. Their median lifetime is 10 Myr [7]. Most of them end up into the Sun, or are ejected from the Solar System, while about 10-15 % collide with a terrestrial planet, in particular the Earth or Venus. Objects in near-Earth space are a precious source of information as they represent a mixture of the different populations of small bodies, *i.e.* main-belt asteroids and cometary nuclei, and provide a link with meteorites [8,9]. They have the advantage of evolving on orbits that make them much more accessible for scientific research and space missions than small bodies of other, more distant populations (comets and main-belt asteroids) from which they have originated [10]. Hence, achieving an enhanced knowledge of NEAs will provide insights to improve our scientific knowledge of the formation of planetary systems. Moreover, the NEA population presents a high degree of diversity as revealed by ground-based observations. To date, more than 10 major spectral classes have been identified [11].

The main goal of the MarcoPolo-R mission is to return primitive NEA material for detailed analysis in ground-based laboratories. The limited sampling provided by meteorites does not offer the most primitive material available in near-Earth space. More primitive material, having experienced less alteration on an asteroid, is expected to be more friable and to not survive atmospheric entry in any discernible amount. The small sample successfully returned by the JAXA mission Hayabusa is confirmed as coming from a processed S-type asteroid.

The large international interest for sample return missions to primitive asteroids is demonstrated by recent mission projects approved for launch by several space agencies: NASA selected the OSIRIS-REx mission in the New Frontiers program for launch in 2016 and a return to Earth in 2023, while JAXA selected the Hayabusa 2 mission for launch in 2014/2015 and a return to Earth in 2020. Given the diversity of the objects chosen as targets and the different sampling strategies adopted by various missions, different material is likely to be sampled by each mission. Thus, it is important that several sample return missions are sent to different targets, using various sampling methods, in order to enhance our knowledge of the diversity of primitive bodies.

MarcoPolo-R will allow European scientists to study some of the most primitive materials available to investigate early Solar System formation processes, returned from a target with known geological context. MarcoPolo-R will provide scientific results that are crucial to answer the following key questions:

1. What is the origin and evolution of material in the early solar system?
2. What are the physical properties and evolution of the building blocks of terrestrial planets?
3. Do primitive NEAs contain pre-solar material yet unknown in meteoritic samples?
4. How do organics in primitive NEAs relate to the origin of life on Earth?

Remote sensing gives only the most superficial information on the surface composition. Consequently, answers to these fundamental questions require measurements with exceptionally high precision and sensitivity. The return of samples to terrestrial laboratories, in which instruments are unconstrained by mass, power, stability etc., is essential. In particular, laboratory techniques can be used to date the major events in the history of a sample and investigate the organic components.

MarcoPolo-R will provide detailed knowledge of the physical and compositional properties of a member of the population of Potentially Hazardous Asteroids (PHA), which is an important contribution to mitigation studies. It will return a bulk sample from an organic-rich primitive asteroid to Earth for laboratory analyses, allowing us to explore the origin of planetary materials and initial stages of habitable planet formation.

2. *Scientific Requirements*

MarcoPolo-R will provide [12] fundamental elements to answer the four key science questions described in the previous section and reported in Table 1 together with the related scientific objectives.

The sample would provide a legacy for future generations of scientists with the potential for development and application of new analysis techniques and instrumentation designed to address as-yet unexplored aspects of planetary science.

In addition, in-situ observations, and surface measurements shall be made to provide local and global geological and physical context for the returned sample.

Table 1: *Science questions and objectives, with measurements and methods to be used to address them* **[12]**.

Science Questions	**Science Objectives**	**Measurements**	**Method**
1. What is the origin and evolution of material in the early solar system?	A. Characterize the chemical and physical environment in the early solar nebula B. Define the processes affecting the gas and the dust in the solar nebula C. Determine the timescales of solar nebula processes	Bulk chemistry. Mineralogy, petrology. Isotopic chemistry in inclusions (*e.g.*, chondrules or CAIs), matrix; pre-solar grains and volatiles, water.	Sample analysis.
2. What are the physical properties and evolution of the building blocks of terrestrial planets?	D. Determine the global physical properties of an NEA E. Determine the physical processes, and their chronology, that shaped the surface structure of the NEA F. Characterize the chemical processes that shaped the NEA composition (*e.g.* volatiles, water) G. Link the detailed orbital and laboratory characterization to meteorites and interplanetary dust particles (IDPs) and provide ground truth for the astronomical database	Volume, shape, mass. Surface morphology and geology. Mineralogy, petrology. Isotope geochemistry & chronology. Weathering effects. Thermal properties.	Imaging. Radio Science. Visible and Near-IR spectrometry. Sample analysis. Mid-IR spectrometry.
3. Do primitive NEAs contain pre-solar material yet unknown in meteoritic samples?	H. Determine the interstellar grain inventory I. Determine the stellar environment in which the grains formed J. Define the interstellar processes that have affected the grains	Bulk chemistry. Mineralogy, petrology. Isotopic chemistry in inclusions (*e.g.*, chondrules or CAIs), matrix; pre-solar grains and volatiles, water.	Sample analysis.
4. How do organics in primitive NEAs relate to the origin of life on Earth?	K. Determine the diversity and complexity of organic species in a primitive asteroid L. Understand the origin of organic species M. Provide insight into the role of organics in life formation	Abundances and distribution of insoluble organic species. Soluble organics. Global surface distribution and identification of organics.	Sample analysis. Visible and Near-IR Imaging-spectrometry.

3. Relevance for mitigation

The study of the physical nature of NEAs is relevant to the assessment of the potential hazard imposed by NEA impacts on our planet. NEAs are responsible for most meteorite falls and for the occasional occurrence of major catastrophic impact events. Whatever the scenario, it is clear that the technology needed to set up a realistic mitigation strategy depends upon knowledge of the physical properties of the impacting body. For example, deflecting a body using a kinetic impactor depends on the response of the body to the impact, which in turns depends on the body's physical properties. The momentum transfer efficiency will certainly be very different for an asteroid containing a high level of porosity (at microscale and/or at macroscale) than for an asteroid containing essentially no porosity. Using the concept of a gravitational tractor for mitigation of a NEA impact also requires precise determination of the mass, shape and rotation state of the object. Moreover, some mitigation strategies rely on the ablation of the surface, which also requires knowledge of the compositional and thermal properties of the asteroid.

The return of a surface sample from a NEA by the MarcoPolo-R mission and its subsequent laboratory analysis will not only help answering questions related to planetary formation, but will also provide for the first time a good knowledge of the material properties of a potential impactor. Numerical codes used for simulating asteroid impacts and characterizing the momentum transfer efficiency of a kinetic impactor have up to now used properties of terrestrial materials to model the asteroid, and they would greatly benefit from the measurements of some properties of a real asteroid sample collected on site. Better knowledge of the physical/compositional properties of a whole object and its material properties would then allow an optimization of the mitigation strategies, and MarcoPolo-R can provide a significant contribution to these objectives, in addition to addressing fundamental science goals.

4. Baseline target of MarcoPolo-R: 2008 EV5

The Potentially Hazardous Asteroid 2008 EV5 was discovered in March 2008. It passed very close to Earth (3.2 Million km) in December 2008, making it an exciting target for detailed radar investigation. In fact, it was observed [13] by the Arecibo and Goldstone planetary radars and by the Very Long Baseline Array during December 2008. Radar observations indicated a retrograde rotation with a period of 3.725 ± 0.001 h and an oblate spheroidal shape with a diameter of 400 ± 50 m [13]. 2008 EV5 has a prominent equatorial ridge broken by a concavity about 150 m in diameter (see fig. 1).

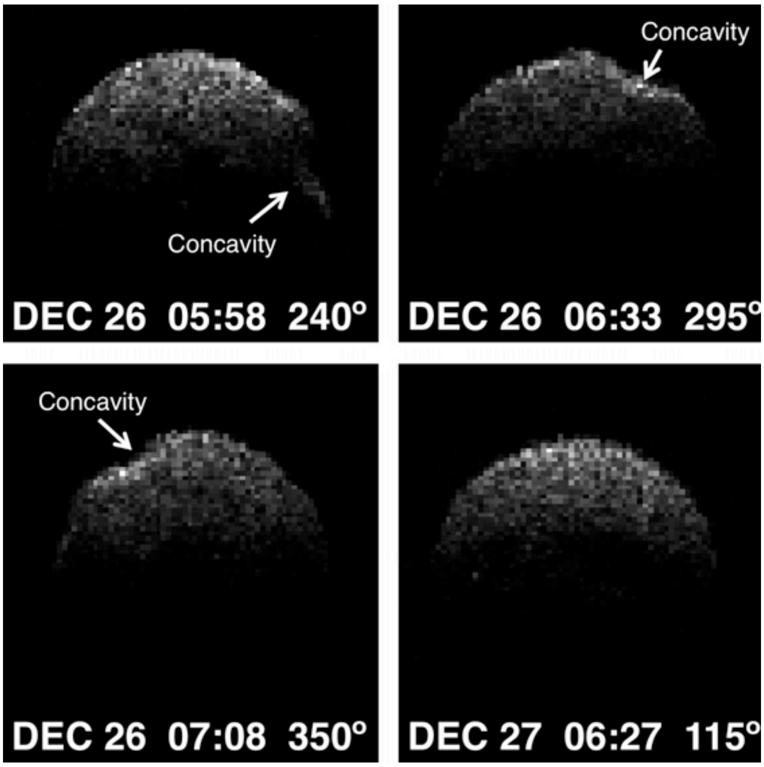

Fig. 1: Delay (range)/Doppler frequency (radial velocity) images of 2008 EV5 from Arecibo data, with the concavity marked by arrows. The labels give the observation time and rotation phase [13].

The target has been observed spectroscopically [14], indicating a primitive asteroid. The spectrum has an overall blue slope and an albedo of 10-12 %. The spectral absorption at 0.48 µm indicates probable alteration by water, and implies that 2008 EV5 is a particularly primitive object that has accreted in a volatile-rich region. The spectrum compares well with CI carbonaceous chondrite meteorites, similar to Orgueil [14].

2008 EV5 exhibits a different composition when compared with other targets, e.g. that of OSIRIS-REx (1996 RQ36) and that of Hayabusa 2 (1999 JU3), which have different spectral characteristics but which both have a significantly lower albedo than 2008 EV5. The investigation of this new target by MarcoPolo-R will therefore provide unique information on primitives bodies.

5. Mission Baseline

The baseline mission scenario of MarcoPolo-R to 2008 EV5 is as follows: a single primary spacecraft (Fig. 2), carrying the Earth re-entry capsule and sample acquisition and transfer system, will be launched by a Soyuz-Fregat rocket from Kourou. The scientific payload includes state-of-the-art instruments, e.g. camera systems for high resolution imaging both from orbit and on the surface, spectrometers covering visible, near-infrared and mid-infrared wavelengths, a radio science experiment, and a small thermogravimetric analyser.

All of these experiments are defined based on scientific requirements and the associated measurements to be carried out at the asteroid, which are structured and classified into three main phases: ‘global characterization’, ‘local characterization’, and ‘sample context measurements’:

- ‘Global characterization’ means measuring the properties of the whole NEA, on a global scale;
- ‘Local characterization’ is the characterization of dedicated areas identified as potential sampling sites;
- ‘Sample context measurements’ are measurements being performed at the actual sampling site.

The global characterization of the body is required to obtain as complete a picture as possible of the physical nature of the target NEA in order to relate the properties of the sample to those of the parent body. Moreover, for the overall success of the mission, the global characterization will allow for the selection of a number of surface areas as potential locations for the intended surface sampling.

Mission profiles have been defined every year between 2022 and 2024. ESA and European industries working on the mission design confirmed that there are opportunities to reach the 2008 EV5 target with a short mission duration (round-trip time of 4.5 years).

The mission scenarios use only one Earth fly-by and the fully recurring electric propulsion engines of the lunar SMART-1 mission, a direct escape and a Soyuz-Fregat launch vehicle. A touch and go sampling operation has been selected, making the touchdown and GNC system design relatively simple. The possibility of adding a Lidar for the Guidance Navigation Control (GNC) is under discussion with JAXA.

In the current study of a mission entirely developed by ESA, alternative sampling approaches are being investigated by two selected industry consortia. Moreover, an independent technical study was started in July 2012, concentrating on “Touch and Go” sampling mechanisms. Cutting wheels, scoops and gaseous transport devices are among the mechanisms that are considered.

The ability to perform an efficient sampling of the surface and to return the minimum required amount of material is crucial for the success of the mission. A sample mechanism by APL (Johns Hopkins University), funded by NASA, is also currently under study.

The design proposed for the MarcoPolo-R Earth Re-entry Capsule (ERC) is entirely passive. In order to save costs it does not include a parachute but instead lands at ~45 m/s with the energy being absorbed by a crushable structure. This parachute-less approach is derived from the Mars Sample Return (MSR) mission design. However, the planetary protection requirements for MarcoPolo-R are less stringent and therefore such a capsule has a much simpler design than for MSR as no bio-container needs to be accommodated. The design was optimized to meet MarcoPolo-R mission needs while preserving key characteristics for high reliability. The final configuration of the ERC will depend on the outcome of the industry studies.

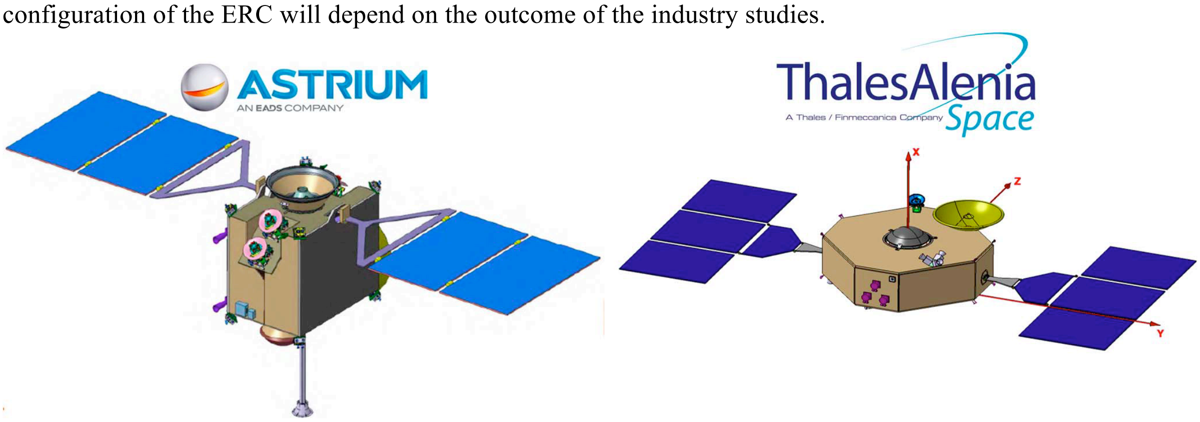

Fig. 2. Possible spacecraft designs as studied by the two competiting European industries (Astrium and ThalesAlenia Space).

6. Conclusions

The baseline target (PHA 2008 EV5) of MarcoPolo-R presents the benefit of a short mission duration. Europe can thus contribute in a timely manner to the international sample return activities. Overall, the choice of this target leads to a significant simplification of the mission design compared with the previous target 1996 FG3 (shorter mission, lower cost propulsion system directly re-used from the lunar SMART-1 mission, very simple communication system, lower power needs, much less challenging thermal design, less risk due to the absence of a secondary body, lower re-entry velocity, etc.). Because of its observed characteristics and dynamical properties, this target offers both unique science and the minimum cost mission design.

MarcoPolo-R is one of five candidates in the competition for the M3 mission in the ESA Cosmic Vision program. The final selection of one of these missions will occur in February 2014 for launch in 2022-2023. The mission cost for ESA must be about 500 million Euros (which includes the launcher and spacecraft, but not the science payload funded by national agencies). The aim of the industrial studies is to design the best mission to reach the science objectives, while keeping the budget below the cost cap.

MarcoPolo-R will return a bulk sample from an organic-rich asteroid to Earth for laboratory analyses, allowing us to:

- Characterize a Potentially Hazardous Asteroid
- Identify and characterize the organics and volatiles in a primitive asteroid
- Explore the origin of planetary materials and initial stages of habitable planet formation

The MarcoPolo-R mission, in addition to addressing exciting science goals, also involves European technologies for which technical development programs are well under way. It is the ideal platform to (i) demonstrate innovative capabilities such as: accurate planetary navigation and landing, sample return operational chain; (ii) prepare the next generation of curation facilities for extra-terrestrial sample storage and analysis; (iii) develop a high-speed re-entry capsule; (iv) pave the way as a pathfinder mission for future sample returns from other planetary bodies.

MarcoPolo-R will ensure that European laboratories involved in sample analysis retain world-class facilities spanning the entire breadth of expertise required for the scientific success of the mission. MarcoPolo-R will, in addition, involve a large international community covering a wide range of scientific disciplines (Planetology, Astrobiology, Cosmochemistry, etc…) and is expected to generate tremendous public interest.

Given the foreseen diversity of small-body compositions, we will only achieve a comprehensive knowledge of asteroid materials by returning samples. The public outreach possibilities of MarcoPolo-R are considerable because of the enormous fascination of the general public for asteroids. On the strategic and political front there is also considerable interest in prediction and mitigation of a NEA impact.

7. Acknowledgements

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