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MarcoPolo-R mission : Tracing the origins

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Abstract

MarcoPolo-R is a sample return mission to a primitive binary Near-Earth Asteroid (NEA) selected for the Assessment Study Phase (2011-2013) of M3 class missions in the framework of ESA's Cosmic Vision (CV) 2 programme. The mission will answer to the fundamental CV questions "How does the Solar System work?" and "What are the conditions for life and planetary formations?".

1. Introduction

Unlike the planets, small bodies retain evidence of the primordial solar nebula and the earliest solar system processes that shaped their evolution. They may also contain pre-solar material as well as complex organic molecules that led to the development of life. For these reasons, asteroids and comets have been targets of interest of proposals and missions for over three decades. Only in the laboratory can instruments with the necessary precision and sensitivity be applied to individual components of the complex mixture of materials that forms an asteroid regolith, to determine their precise chemical and isotopic composition. Such measurements are vital for revealing the evidence of stellar, interstellar medium, pre-solar nebula and parent body processes that are retained in primitive asteroidal material, unaltered by atmospheric entry or terrestrial contamination. It is no surprise therefore that sample return missions are considered a priority by a number of leading space agencies. Abundant within the inner solar system and the main impactors on terrestrial planets, small bodies may have been the principal contributors of the water and organic material essential to create life on Earth. Small bodies can therefore be considered to be equivalent to DNA for unravelling our solar system's history, offering us a unique window to investigate both the formation of planets and the origin of life. Moreover, in the current epoch, these small bodies also represent both a potentially rich resource for future space exploration and a threat to the very existence of humankind on Earth.

MarcoPolo-R will allow us to study some of the most primitive materials available to investigate early solar system formation processes. Direct investigation of both the regolith and fresh interior fragments is impossible by any means other than sample return. MarcoPolo-R will provide scientific results that are crucial to answer the following key questions:

1. What were the processes occurring in the early solar system and accompanying planet formation?
2. What are the physical properties and evolution of the building blocks of terrestrial planets?
3. Do NEAs of primitive classes contain pre-solar material yet unknown in meteoritic samples?
4. What are the nature and the origin of the organics in primitive asteroids and how can they shed light on the origin of molecules necessary for life?

The large international interest for sample return missions to primitive asteroids is demonstrated by recent selections made by two of the main space agencies. NASA selected the OSIRIS-Rex mission in the New Frontiers programme 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 targeted objects and the various sampling strategies adopted by different missions, different types and amounts of material will be sampled. It is important that several sample return missions are sent to multiple objects using different sampling approaches, in order to enhance and maximise our knowledge on the diversity of primitive bodies.

2. The baseline target: the binary asteroid 1996 FG3

The main goal of the MarcoPolo-R mission is to return unaltered primitive material from a unique binary asteroid for detailed analysis in European ground-based laboratories.

The baseline target is (175706) 1996 FG3 (a particularly interesting C-type object), which offers an efficient operational and technical mission profile. A binary target also provides enhanced science return. Precise measurements of the mutual orbit and rotation state of both components can be used to probe higher-level harmonics of the gravitational potential, and therefore the internal structure. A unique opportunity is offered to study the dynamical evolution driven by the YORP/Yarkovsky thermal effects. Possible migration of regolith on the primary from poles to equator allows the increasing maturity of asteroidal regolith with time to be expressed as a latitude-dependent trend, with the most-weathered material at the equator. Moreover, sample return from a binary would bring us crucial information: i) that may allow discrimination between the proposed formation mechanisms of binary systems, ii) about the internal composition of the progenitor.

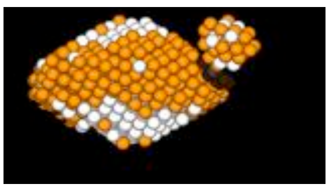

Figure 1: *Image of a simulation of binary formation by YORP spin-up; orange particles were originally located at the surface of the progenitor, white particles were originally below the surface. The pole of the primary is essentially composed of white, initially sub-surface, particles (Walsh K. et al. 2008, Nature 454, 188).*

3. Mission Profile

A single primary spacecraft carrying the Earth Re-entry Capsule (ERC), sample acquisition and transfer system will be launched by a Soyuz-Fregat rocket from Kourou. Several missions have been already studied internally by ESA with launch windows in 2021-2023, and sample return in 2029. They are currently defined as the best options. Earlier or later launches, in 2020 or 2024, also offer good opportunities. Once at the NEA, a number of potential sampling sites (up to 5) are characterized by remote sensing measurements. The spacecraft will then attempt to sample surface material (order of 100g) on the most suitable site (*i.e.* the location yielding the best compromise between science return and risk-mitigation). If the sample collection is not confirmed, up to two additional samplings can be attempted.

The scientific payload includes a camera system for high-resolution imaging, spectrometers covering visible, near-infrared and mid-infrared wavelengths, a neutral-particle analyser, a radio science experiment and optional laser altimeter. If resources are available, an optional lander will be added to perform in-situ characterization close to the sampling site, and possibly internal structure investigations.

4. Conclusion

MarcoPolo-R will return bulk samples from an organic-rich binary asteroid to Earth for laboratory analyses, allowing us to explore the origin of planetary materials and initial stages of habitable planet formation; to identify and characterize the organics and volatiles in a primitive asteroid; to understand the unique geophysics, dynamics and evolution of a binary NEA.

The development of sample return technology represents a crucial element for Europe’s science community and space industry to remain at the level of other main agencies developing these capabilities. The sample will provide a legacy for future generations of scientists with the potential for application of new analysis techniques and instrumentation to address as yet unexplored aspects of planetary science. In addition to addressing the exciting science goals, the MarcoPolo-R mission 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 high-speed re-entry capsule; (iv) pave the way as a pathfinder mission for future sample returns from bodies with high surface gravity.