MARCOPOLO-M5 – A SAMPLE RETURN MISSION TO A D-TYPE NEAR EARTH ASTEROID PROPOSED TO THE ESA COSMIC VISION M5 CALL.

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Introduction: MarcoPolo-M5 is proposed to the M5 launch opportunity in the ESA Cosmic Vision program. The M5 missions are for launch in 2029-2030. Within this window, an opportunity exists for a very short mission duration sample return to a primitive near-Earth asteroid identified as 1993 HA. The visible-near infra-red spectra of 1993 HA is a typical D-type spectra [1] and MarcoPolo-M5 would be the first sample return mission to a primitive D-type asteroid.

D-types are the most abundant asteroids beyond the outer edge of the main asteroid belt, in particular concentrated in the Trojan population located in the L4 and L5 Jupiter-Sun Lagrangian points [2]. The D-type asteroids contain abundant organics and volatiles, and are widely believed to be the most primitive “rocky” material present in the solar system. They appear to have been formed in a region of the protoplanetary disk rich in frozen volatiles, possibly as far as the Kuiper Belt, and have been subsequently captured in their present locations following the migration of the giant planets [3]. Further perturbations provide a steady stream of this most primitive material into near-Earth orbits that can then be readily accessed by spacecraft.

D-type asteroids may represent the link in the continuum between comets and primitive asteroids, such as the C type asteroids that now dominate the Main Asteroid Belt and comets that formed at greater heliocentric distance in very volatile-rich regions of the outer disk [4]. Indeed, the spectra of the dark surfaces of comet 67P/CG [e.g. 5] is very similar to that of D-type asteroids [6], indicating possible common origins.

Currently, we have little or no access to D-type asteroid material. Only three small and rather fragile meteorites have been tentatively linked to D-type asteroids, indicating that D-types are indeed composed of particularly primitive material that is unable to survive to the surface of the Earth in large macroscopic samples. Indeed, the truly primitive nature of the D-type asteroids may be best indicated by the most primitive interplanetary dust particles, that contain prisitne materials recording the earliest stages of solar system formation and have spectra that most closely match that of D-type asteroids [7,8]. The fluffy aggregate nature of these tiny particles [9] is very similar to that observed emenating from the surface of comet 67P/CG, providing further evidence of closely related origins for D-type asteroids and comets.

Science Questions: With this proposal, we address five fundamental questions related to the origin of the solar system and the emergence of Life on planet Earth by studying in-situ a primitive D-type asteroid, and returning to Earth rocks, minerals and organics sampled on this body. The 5 questions can be summarised as such:

1. What was the astrophysical setting of the birth of the solar system?
2. What is the origin of material in the early solar system and how did it evolve?
3. What is the origin of water and the atmophile elements on Earth and other terrestrial planets?
4. What is the nature and origin of organic compounds in the early solar system and their involvement in the origin of life on Earth?
5. What is the nature of D-type asteroids and how do they relate to other classes of asteroids and cometary bodies?

Answers to these fundamental questions require measurements with exceptionally high precision and sensitivity. Such measurements cannot be performed by a robotic spacecraft and therefore require a sample returned to terrestrial laboratories where instrumentation is unconstrained by mass, power, stability etc.

Mission Description: The baseline mission has been developed with the assistance of OHB. The spacecraft is launched by an Ariane 6.2 on a direct escape outbound trajectory to 1993 HA in January 2029. Capatilising on the performance of the latest generation of solar electric propulsion, and a fly-by of Mars on the outbound leg, the total mission duration for the round trip to the asteroid and back to Earth is only 3 years and 7 months. MarcoPolo-M5 arrives at 1993 HA in November 2030 and stays around the asteroid for almost 8 months. During this proximity phase, the NEA is characterised by a suite of instruments, including high resolution multi-spectral imaging camera, visible-near infra red, and thermal infra-red imaging spectrometers, which allows selection of safe and scientifically valuable sampling site candidates. The spacecraft will then perform a number of close approaches to the asteroid surface, decending to an altitude of 250 m, collecting detailed information about each potential sampling site and rehearsing the sampling descent. During one low altitude rehearsal the small FANTINA lander is deployed onto the surface for initial close-up characterisation of the asteroid surface and characterisation of the interior structure. A number of instruemnts provide detailed information about the volatiles present in the surface environment and the de-gassing and sputtering rates from the surface. Finally, the spacecraft carries out a "touch and go" sampling operation on the asteroid surface with the capability of performing three sampling attempts. The spacecraft departs the asteroid in June 2031 to return to Earth where it releases the re-entry capsule, which enters the atmosphere at a speed of ~11.6 km s^{-1} and proposed landing at the Woomera Test Range (Australia) in September 2032.

Most of the science return from this mission will be derived from the detailed investigation of the samples in terrestrial laboratories. The final mission phase will involve initial characterisation of the sample in the Sample Receiving and Curation Facility followed by a preliminary investigation by selected teams of leading scientists. A programme for handling and curating planetary material returned by space missions will be developed for the first time in Europe, building upon extensive preparation work already underway, such as the Euro-Cares sample H2020 curation study [10]. A fraction (at least 50 %) of the returned sample will be stored in the curation facility for future generations of scientists and advances in analytical instrumentation.

Heritage: MarcoPolo-M5 is a multi-disciplinary mission in a new era of high international interest in sample return missions to primitive asteroids. MarcoPolo-M5 is now a mature M-class mission with low cost-related risk, benefitting from the previous MarcoPolo [11] and MarcoPolo-R [12] mission studies. The key sampling and return capabilities, i.e. asteroid navigation, touch and go, sampling mechanism and the re-entry capsule have all benefited from industrial studies and breadboarding projects during the MarcoPolo-R study and other small body sample return mission concept studies (e.g. Phobos sample return), maturing TRL and identifying technology development solutions. Further enhancement of capability from international partners can be considered.

Context: MarcoPolo-M5 benefits from, and provides added value to, other missions to primitive asteroids. Hayabusa2 and OSIRIS-REx will investigate and return material from C- and B-type asteroids respectively. These spectral types are predominatly found in the Main Asteroid Belt, and therefore likely formed closer to the Sun than the D-type target of MarcoPolo-M5, but likely are part of a continuum of materials extending to particularly volatile-rich comets. The Rosetta rendezvous mission has provided amazing detail of comet 67P/ Churyumov-Gerasimenko, but the payload of such missions preclude obtaining the high precision, high sensitivity measurements required to address the main science objectives of MarcoPolo-M5. Therefore, MarcoPolo-M5 can greatly enhance the science from Rosetta by providing detailed information about the most primitive materials. Similarly, the recently selected Lucy mission [13] that will fly by a number of Trojan asteroids, including some D-type asteoids, will provide an excellent new insight into the nature of the most primitive bodies and provide a baseline context for the samples returned by MarcoPolo-M5. In return, the detailed knowledge determined from the returned samples will be able to provide new insight into the materials observed from afar during each of Lucy's flybys.

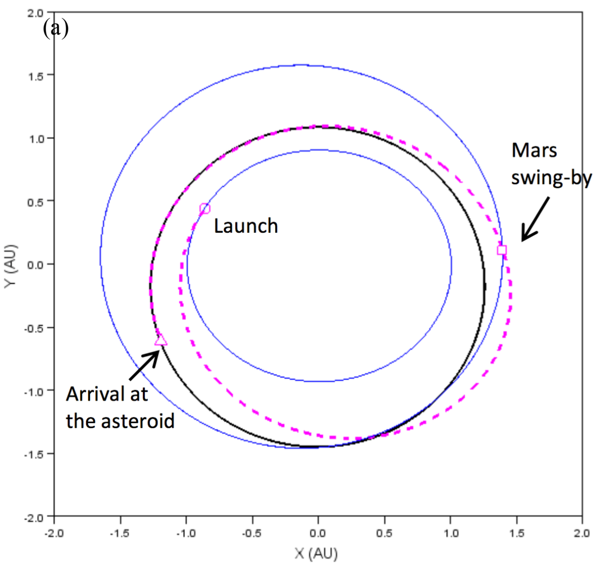

Figure 1*: Orbit for the outbound transfer for the baseline target 1993 HA for MarcoPolo-M5. Total mission duration = 3.6 years, and provides almost 8 months at the asteroid for science operations and returns to Earth with a re-entry velocity of 11.6 kms^{-1}. Courtesy: CNES*

MarcoPolo sample return has been supported by a large community of over 600 scientists for many years. For an update visit: www.open.ac.uk/marcopolo-m5

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