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DOCUMENT

MarcoPolo-R Science Requirements Document

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Table of contents:

1 INTRODUCTION

1.1 Scope

This document describes the detailed scientific requirements for the MarcoPolo-R mission. These requirements are derived from discussions by the MarcoPolo-R Science Study Team (SST) and are based on the scientific objectives as described in the MarcoPolo-R Proposal to ESA's Cosmic Vision programme (RD 01).

The first issue of this document serves as a starting point for an ESA-internal study in the Concurrent Design Facility (CDF). After that it may need an update before the start of the industrial study phase (Issue 2).

In case of the selection of this mission for implementation, another update of the document may be required to reflect updates in the scientific progress during the time of the study, resulting in an Issue 3.

1.2 Applicable Documents

AD 01 MarcoPolo-R Mission Requirements Document, to be written

1.3 Reference Documents

RD 01 MarcoPolo-R – Near-Earth Asteroid Sample Return Mission, Proposal to ESA's Cosmic Vision Programme, Nov 2010

RD 02 Payload Definition Document, to be written

RD 03 Assessment Study Report ('Yellow Book'), to be written

1.4 Acronyms

AD	Applicable Document
CDF	Concurrent Design Facility
ESA	European Space Agency
NEA	Near-Earth Asteroid
RD	Reference Document
SST	Science Study Team
MP-R	MarcoPolo-R

2 MISSION OBJECTIVES

The main objective of the MarcoPolo-R mission is to return a sample from a near-Earth asteroid (NEA) of primitive class to the Earth for detailed laboratory analysis. Scientific investigations will be included to make observations with the following priorities:

i. To enable the safe operation and manoeuvring of the spacecraft in close proximity to the NEA and safe collection of the sample.

ii. To place the sample in its global and local context.

iii. To provide complementary science results not achievable from the sample itself.

The proposal lists the following top-level science topics where MarcoPolo-R shall contribute by in-situ and laboratory analysis of the returned sample to a better understanding of:

(1) the origin of the solar system and planets,

(2) the formation and evolution of NEAs,

(3) astrobiology.

In the following text, 'shall' refers to a requirement which is a must for fulfilling the science goals, whereas 'should' indicates that the science goals can be fulfilled without this requirement, but it would be beneficial to the mission science return to obtain this goal. A 'should' requirement must not drive the mission design.

All requirements are numbered. The numbers were incremented initially in steps of 10 to allow inserting requirements at appropriate locations. When requirements were deleted, the numbers were not changed to allow traceability.

3 SCIENCE REQUIREMENTS

The main requirement is

to return a sample from a primitive[1] near-Earth asteroid

that will allow the study of the formation of the solar system and the planets, the characterisation of a near-Earth asteroid as a representative of a primitive solar system body, and contribute to the field of astrobiology.

In addition, scientific information shall be collected to provide the context of the sample.

During the writing of the MarcoPolo-R proposal (RD 01), the following top-level science goals and derived science objectives were developed. All requirements as described in this document can be linked to the objectives and the goals.

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[1] 'Primitive asteroids' are selected based on their albedo and, if available, spectral class, by the Science Study Team.

All the requirements given in this document are applicable for any target. In the case of a binary asteroid, they are applicable for the primary (larger) object. Section 3.7 specifically addresses the case of a binary asteroid.

The four *science goals* of MarcoPolo-R are:

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 *scientific objectives* of the mission are:

A. Characterise 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

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. Characterise the chemical processes that shaped the NEA composition (*e.g.* volatiles, water)
G. Link the detailed orbital and laboratory characterisation to meteorites and interplanetary dust particles (IDPs) and provide ground truth for the astronomical database

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

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

The following table links science objectives to the top-level science goals and gives a keyword for the needed measurements and methodologies. For a more explicit discussion, see the proposal (RD 01).

Table 1: Science goals, objectives and related measurements; and the method to perform the measurement.

Science Goals	Science Objectives	Measurements	Method
1. What were the processes occurring in the early solar system and accompanying planet formation?	A. Characterise 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; presolar 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. Characterise the chemical processes that shaped the NEA composition (*e.g.* volatiles, water) G. Link the detailed orbital and laboratory characterisation 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 Radar absorption (*) Seismic waves (*)	Imaging, laser altimetry (*) Radio science Visible and Near-IR spectrometry Sample analysis Neutral particle analysis Mid-IR spectrometry Surface sensors (*) Penetrating radar (*) Seismic Exp. (*)
3. Do NEAs of primitive classes 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; presolar grains and volatiles, water	Sample analysis
4. What are the nature and origin of organics in primitive asteroids and how can they shed light on the origin of molecules necessary for life?	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

(*): optional

In the following, we at first give requirements for the target selection and then the properties of the returned sample. After that, we distinguish between 'global characterisation', 'local characterisation', and 'sample context':

- 'Global characterisation' means to measure the properties of the whole NEA, on a global scale;
- 'Local characterisation' is the characterisation of up to 5 dedicated areas which are identified as potential sampling sites (see SR-10);
- 'Sample context' are measurements being performed at the actual sampling site.

Table 2 gives an overview of the required orders of resolution for the different scenarios.

Table 2: Resolution requirements for global characterisation, local characterisation, and context measurements.

	Spatial resolution for imaging in the visual	Spatial resolution for VIS/IR spectrometer	Spatial resolution for mid-IR instrument
Global characterisation	Order of[2] dm	Order of m	Order of 10 m
Local characterisation	Order of mm (*)	Order of dm	Order of dm
Context measurements	hundred μm	-	-
(*): For a representative area within the landing accuracy of the spacecraft			

3.1 Target selection

Requirements on the taxonomic class of the NEA are important to define the mission scenario. The following bullets summarize the required properties of the target. The current reference target is the binary asteroid 1996 FG3. The list of selected potential targets, for the given timeframe, is given in Appendix A, p. 16.

TS-10: Target class: The target shall be a primitive NEA. Note, however, confirmation of the final target by the Science Study Team shall take place at a later stage.

TS-20: Target size: There is no strong scientific requirement for a minimum target size. However, the target should be of a size such that:

[2] "order of dm" means from ~0.3 to 3 dm, similarily for other scales.

i) It should have sufficient gravity to allow the determination of the gravity field to an accuracy good enough to provide some constraint to the internal structure (*e.g.* determine the J2 coefficient to 10 %).

ii) It is bright enough for fundamental properties (size, shape, albedo, rotation) to be estimated from ground-based observations.

As no precise numbers can currently be given for the above points, for the purpose of this study a constraint for the absolute visual magnitude of $H \leq 21$ mag shall be assumed, corresponding to a diameter $D \geq 340$ m for a representative primitive body assuming a visual geometric albedo of 0.06.

3.2 Sample-related requirements

To achieve the scientific goals of the mission, the following requirements shall be fulfilled by the sample:

SA-10: It shall be possible to characterize up to 5 potential sampling sites before the actual sampling. “Characterize” means:

(a) Determine the particle size distribution of the regolith down to scales of the order of a millimetre;

(b) Determine the rough mineralogical composition of the order of a decimetre;

(c) Determine the thermal skin depth indicative of regolith properties.

SA-020: It shall be possible to perform multiple sampling attempts (up to 3).

SA-030: The sampling device shall have the capability to acquire a minimum mass of the order of a hundred grams and shall return them to Earth.

SA-040: After collection, the maximum temperature reached by the sample should not exceed +40 °C for long durations. For short durations of less than 1 minute, a temperature of up to +80 °C is acceptable.

SA-050: The sampling device shall have the capability to acquire a selection of cm-sized fragments, plus a large number (minimum several grams) of small (hundreds of µm-sized to mm-sized) particles.

SA-060: Highest priority for sampling shall be given to a target area which, from the global and local characterization of the NEA, appears to contain the most primitive material. This may be anywhere on the asteroid.

Contamination[3]:

SA-070: During collection and storage (departure from NEA, cruise, Earth re-entry, ground retrieval and transfer to curation facilities) the sample shall be maintained free of organic and particulate contamination. The number of contaminating molecules deposited on the asteroid surface by the propulsion system shall be lower than 10^{+14} / cm^2 (goal 10^{+13} / cm^2).

SA-080: The spacecraft materials affecting the sample collection and storage shall be free of organic compounds or compounds that may react to materials which can possibly contaminate the sample to a limit of tbd.

SA-090: After being placed in the sample container, the sample shall not be contaminated by dust or liquid particles larger than 1 µm

SA-100: Until the sample arrives in the curation facility, it shall be kept free of moisture from the atmosphere (goal: avoid all terrestrial gases) such that less than 0.1 ppm terrestrial water is present in the sample.

SA-110: The possible contaminants (*e.g.* propellant, S/C outgassing, etc.) shall be tracked in-situ (*e.g.* by using witness plates).

SA-120: During the complete manufacturing process of the spacecraft, procedures shall be in place to keep all parts of the spacecraft clean to a level to be specified.

SA-130: The sampling mechanism and container shall be kept clean to a level to be specified and the cleanliness shall be monitored from the very beginning of the manufacturing.

SA-140: The materials used in the spacecraft fabrication and handling shall be archived.

SA-150: The sample should not be subjected to magnetic fields >200 µT (microTesla).

3.3 Global characterisation requirements

'Global characterisation' means to measure the properties pertaining to the entire NEA. Section 3.4, lists requirements for the local characterisation, which is meant to study up to 5 potential sampling sites in sufficient detail to decide that a sampling is useful. When the actual sample is taken, context measurements shall be performed, see Section 3.5.

In detail, the following requirements need to be fulfilled for the global characterisation:

GR-010: The complete surface of the NEA shall be imaged in at least 3 different colours, in the visible range with a spatial resolution of the order of decimetres, and with local solar elevation angle between 30 and 60° (Note: it is acknowledged that depending on the

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[3] A 'contaminant' can be any material which is not from the asteroid.

rotation axis of the asteroid there may be areas which cannot be imaged due to illumination constraints).

GR-020: The complete surface of the NEA shall be imaged in the visible and near-IR wavelength range from 0.4 to 3.3 μm and with a mean spectral resolution of λ/Δλ of the order of 200 and a spatial resolution of the order of metres to characterize the mineral properties of the surface (Note: it is acknowledged that depending on the rotation axis of the asteroid there may be areas which cannot be imaged due to illumination constraints).

GR-030: A shape model of the NEA shall be obtained with an accuracy of typically 1 m in height and spatial resolution with respect to the centre of mass.

GR-040: The spatial resolution of the relative 3-D topography (*i.e.* in relative coordinates) should be determined to an accuracy of the order of decimetres.

GR-050: The mass of the NEA shall be determined with an accuracy of about 1 %..

GR-060: The surface temperature of the complete NEA shall be derived to an accuracy of at least 5 K (goal 1 K) above 200 K (tbd). The spatial resolution shall be of the order of 10 m at a number of rotational phases from which the thermal inertia can be determined to a precision of better than 10 %

GR-070: The complete surface of the NEA shall be imaged in the mid-IR with a spatial resolution of the order of 10 m or better and with a spectral resolution of λ/Δλ of the order of at least 200 to determine the wavelength dependent emissivity, and hence identify mineral features in the range 8 – 16 μm (goal 5 – 25 μm).

GR-080: The flux, speed, direction and mass of atomic/molecular particles escaping from the surface should be measured to detect products of solar wind sputtering or other active release processes. Then, the energy range from 0.01 to 1 keV shall be covered with an energy resolution of about 25 % and an angular resolution of 5° x 5°; the particles with energies <0.01 keV shall be measured with m/Δm of about 50.

3.4 Local characterisation requirements

'Local characterisation' is the characterisation of up to 5 dedicated areas which are identified as potential sampling sites (see SA-010). The following detailed requirements apply:

LR-010: A representative area within the expected landing area ellipse (goal: entire ellipse) shall be imaged in the visible in at least three colour filters, with a spatial resolution of the order of millimetres.

LR-020: A representative area within the expected landing area ellipse (goal: entire ellipse) shall be imaged in the visible and near-IR wavelength range to characterise the mineral properties of the surface with a mean spectral resolution of λ/Δλ of the order of 200 and a spatial resolution of the order of decimetres to characterize the mineral properties of the surface.

LR-030: A representative area within the expected landing area ellipse (goal: entire ellipse) shall be imaged in the mid-IR with a spatial resolution of decimetres and a spectral resolution of at least $\lambda/\Delta\lambda$ of the order of 200 or better to determine the wavelength dependent emissivity, and hence identify mineral features in the range 8 – 16 µm (goal 5 – 25 µm).

LR-040: (As GR-070) The flux, speed, direction and mass of atomic/molecular particles escaping from the surface should be measured. Then, the energy range from 0.01 to 1 keV shall be covered with an energy resolution of about 25 % and spatial resolution at surface about 10 m; the particles at energy <0.01 keV shall be measured with $m/\Delta m$ of about 50.

3.5 Sample context requirements

SC-010: The regolith size distribution of the actual sampling site shall be measured before and after sampling to sizes as small as 100 µm (goal: 15 µm) in an area about 5 times larger than the area sampled by the sampling device.

SC-020: An additional "local characterisation" shall be performed after the sample collection (*i.e.* fulfil LR-010 to LR-030 again), for the site where the sample was collected.

SC-030: The images taken by the navigation camera (if any) during the descent should be made available to scientists upon request.

3.6 Other requirements

OR-010: It shall be possible to calibrate the colour response of the instruments, by providing a calibration target (if mission analysis foresees a lunar flyby, allow imaging of Apollo 16 landing site).

OR-020: After sample collection, a device or method shall allow verification that a suitable sample has been collected, giving a rough estimate of the volume or mass of the sample.

OR-030: The sample shall not be exposed to a shock load higher than 800 g.

OR-040: If the mission scenario foresees any planetary flyby, it shall be possible to switch on all payload elements for testing.

3.7 Binary NEA science requirements

The following requirements are applicable only in the case of a binary asteroid.

BI-010: The goal of the mission shall be to perform a global characterisation of the secondary similar to the primary (as given in GR-010, GR-020, GR-030, GR-035, GR-050) as much as possible without compromising the characterisation of the primary in the available mission duration. Note that it is not expected to fulfil GR-040 (mass determination to 1 %.

BI-020: The local characterisation can potentially be done on the primary or secondary object.

BI-030: The orbital and rotational states of the two objects shall be characterised to an accuracy high enough to be able to constrain the higher-level harmonics of the gravitational potential (value tbd). This will allow to constrain the internal structure.

3.8 Additional NEA science requirements

These requirements describe the characterisation of the NEA as described in Section 2, bullet iii (thus 'category III') which offer additional NEA science.

These have lower priority than the requirements given previously. It is acknowledged that with the current mission design (summer 2011) points AS-010 and -030 are unlikely to be considered.

AS-010: The inner structure of the NEA should be constrained, with the goal of doing this to a depth of about 100 m and a spatial resolution of about 10 m.

AS-020: The J2 terms of the gravitational field should be determined with an accuracy of 10 %.

AS-030: It should be possible to do near-surface investigations of several areas on the NEA (*e.g.* by hopping or hovering with a Lander).

AS-040: Complete images obtained with the Star Trackers and navigation camera (if any) should be made available to scientists upon request.

Note that additional requirements for binary targets will be added in a future version of the document.

3.9 Requirements to curation facility

CU-010: The curation facility shall maintain the sample free of organic and particulate contamination. The number of contaminating molecules and particulates deposited on the sample surface during an expected stay time of 2 years shall be lower than 10^{13} cm^{-2} (goal 10^{12} cm^{-2}) and lower than 1 particle of size 1 µm on 1 cm^2, respectively.

CU-020: After arrival in the curation facility and extraction from the sample container, the sample shall be kept and processed in an environment equivalent to ISO class 4 (ISO 14644-1).

CU-030: After arrival in the curation facility, the sample shall be kept free of moisture from the atmosphere such that less than 0.01 ppm terrestrial water is present in the sample after an assumed stay time of 2 years.

CU-040: It should be possible to manipulate sample volumes from $5 \cdot 10^{-7}$ to 4 cm^3.

CU-050: The sample shall be classified through preliminary characterization according to its size and morphology (accuracy at least 0.5 μm), weight (accuracy 1% in the microgram to gram range), and mineralogical phase (accuracy at least 1 % vol)(*tbc*).

CU-060: The possible contaminants shall be tracked and monitored in-situ (*e.g.* using witness plates).

CU-070: Parts of the sample shall be stored for 50 years in clean conditions (goal: in vacuum).

4 APPENDIX A – LIST OF POSSIBLE TARGETS

The current baseline target is the binary asteroid 1996 FG3. The following table lists the selected possible backup targets which were identified as good candidates for a Soyuz-launch during the CDF study. Either their size and rotation period is known, or it is possible to characterise them before the timeframe 2020-22.

These additional targets present the following features (more can be proposed if they fulfil the criteria below):

- Albedo < 10%
- Spectral classes: D, T or C-type binaries
- Absolute magnitude < 21
- perihelion > 0.6 AU, aphelion < 3 AU
- inclination < 10 degrees

Table 3: List of possible backup targets.

Number	Prelim. Designation	Taxonomic spectral class	Estimated diameter in km (*)	Rotation period in hours
162998	2001 SK162	T, D	1.94	68
164184	2004 BF68	C	?	5.66
228502	2001 TE2	C, B/C	1.90	?
	2001 SG286	D	?	?
	2003 VO2	?	?	?
	2006 KV89	?	?	?
	2008 DG5	?	?	?
	1999 XR2	?	?	?
	2008 EV5 (tbc)	C, X	0.4	3.725

(*) calculated from the absolute visual magnitude *H* assuming an albedo of 0.06.