MARCOPOLLO- R NEAR EARTH ASTEROID SAMPLE RETURN MISSION

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MarcoPolo-R was selected
(one out of four)

- Study Manager
  - David Agnolon (ESA - Advanced Studies and Technology Preparation Division)
- Study Scientist
  - Detlef Koschny (ESA - Solar System Missions Division)
- Study Payload Manager
  - Jens Romstedt (ESA - Advanced Studies and Technology Preparation Division)
- Science Study Team (SST):
  - A. Barucci (F), J. Brucato (I), H. Böhnhardt (D), E. Dotto (I), P. Ehrenfreund (NL), I. Franchi (UK), S. Green (UK), L. Lara (E), B. Marty (F), P. Michel (F) + A. Cheng (USA)
- Tasks of the SST:
  - To advise and to monitor the study from a scientific point of view
MarcoPolo-R is a sample return mission recommended by ESA as one of the concepts to be studied in the framework of Cosmic Vision 2 M3 missions with launch in 2020-2022.

MarcoPolo-R is a mission to a primitive Near-Earth Asteroid (NEA). It will rendezvous with a primitive NEA, scientifically characterize it at multiple scales, and return a unique unaltered sample to Earth.

The ESA assessment study started on May 2011 and will continue until middle 2013. Two European aerospace companies will study in detail the project.
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 organics in primitive asteroids and how can they shed light on the origin of molecules necessary for life?

Answers to these fundamental questions can be derived by laboratory measurements on a sample from a primitive NEA.
Scientific Objectives

A. Characterise the chemical and physical environments 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 of 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
Science Questions and Measurements

- What were the processes occurring in the early solar system and accompanying planet formation?
- 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?
- Do NEAs of primitive classes contain presolar material yet unknown in meteoritic samples?
- What are the physical properties and evolution of the building blocks of terrestrial planets?

Material composition

- Variation of composition with geological context
- Effect of space weathering and collisions on NEA composition

Elemental/isotopic composition
Nature of organics
Mineralogy
Surface morphology
Mass, gravity density

Laboratory study of returned sample
Measurements at NEA

Interior structure
**Mission and Spacecraft**

**Prime Target**

1996 FG3 Binary System

Low albedo, C-type

### Orbital and Physical Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit type</td>
<td>Apollo</td>
</tr>
<tr>
<td>Semimajor axis</td>
<td>1.054 AU</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.350</td>
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<tr>
<td>Inclination</td>
<td>2.0</td>
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<tr>
<td>Perihelion distance</td>
<td>0.685 AU</td>
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<tr>
<td>Aphelion distance</td>
<td>1.423 AU</td>
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<tr>
<td>Absolute magnitude (H)</td>
<td>18.0</td>
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<tr>
<td>Diameter</td>
<td>~1.8 km</td>
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<tr>
<td>Rotation period</td>
<td>3.59 h</td>
</tr>
<tr>
<td>Pole direction</td>
<td>$\lambda=242\pm96$ deg, $\beta=-84(+14/-5)$ deg</td>
</tr>
<tr>
<td>Lightcurve amplitude</td>
<td>&lt;0.1 mag</td>
</tr>
<tr>
<td>Spectral class</td>
<td>C-class</td>
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</tbody>
</table>

### Nominal Science Payload

<table>
<thead>
<tr>
<th>Payload Type</th>
<th>Weight [kg]</th>
<th>Volume [mm]</th>
<th>Power [W] average</th>
<th>Data volume single measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Angle Camera (WAC)</td>
<td>2.8</td>
<td>237x172x115</td>
<td>11.5</td>
<td>67 Mbit</td>
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<td>Narrow Angle Camera (NAC)</td>
<td>0.92</td>
<td>520x400x197</td>
<td>13.5</td>
<td>67 Mbit</td>
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<tr>
<td>Close-Up Camera (CUC)</td>
<td>0.82</td>
<td>364x78x56</td>
<td>12.5</td>
<td>67 Mbit</td>
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<tr>
<td>Laser Altimeter</td>
<td>4.0</td>
<td>150x100x100</td>
<td>22</td>
<td>80 bit/shot</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Payload Type</th>
<th>Weight [kg]</th>
<th>Dimensions [mm]</th>
<th>Power [W] average</th>
<th>Data volume single measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Near Infrared spectrometer (VNIR)</td>
<td>3.5</td>
<td>270x110x90</td>
<td>15.0</td>
<td>0.45 Mbit</td>
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<tr>
<td>Mid-Infrared spectrometer (MIR)</td>
<td>3.0</td>
<td>160x220x370</td>
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<td>360 Mbit</td>
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<tr>
<td>Radio Science Experiment (RSE)</td>
<td></td>
<td></td>
<td></td>
<td>Data recorded in the ground station in real time</td>
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<tr>
<td>Neutral Particle Analyzer (NPA)</td>
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### Complementary Science Payload

<table>
<thead>
<tr>
<th>Payload Type</th>
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<th>Volume [mm]</th>
<th>Power [W] average</th>
<th>Data volume single measurement</th>
</tr>
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<tr>
<td>Asteroid Charge Experiment (ACE)</td>
<td>1.465</td>
<td></td>
<td>1.5</td>
<td>170 bit/s</td>
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<tr>
<td>Alpha Particle X-ray Analyzer (APXS)</td>
<td>0.35</td>
<td>52(0) x 84</td>
<td>1.5</td>
<td>192 kbit</td>
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<tr>
<td>Thermal Sensor</td>
<td>0.24</td>
<td>20x20x40</td>
<td>0.5</td>
<td>100 bit</td>
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<tr>
<td>Regolith Microscope / IR spectrometer</td>
<td>0.18</td>
<td>26 (2) x 158</td>
<td>1.2</td>
<td>21 Mbit</td>
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<tr>
<td>Lander</td>
<td>16.2</td>
<td>na</td>
<td></td>
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1996 FG3: MarcoPolo-R
Prime Target

- Current apparition of 1996 FG3: approached to 0.101 AU of Earth in November, 2011
- Ongoing campaign to observe in radar, visible, IR
- Preliminary results from current apparition
  - Low thermal inertia (regolith present)
  - Likely 3-µm absorption band (hydrated minerals)
  - Possible visible-near IR spectral slope variation (compositional heterogeneity?)
  - Equatorial ridge seen in radar images, consistent with 1999 KW4-like shape
Arecibo Images of 1996 FG3: 2011 Nov. 20, 0.5 usec x 0.24 Hz, 3 runs/frame

Doppler frequency (0.24 Hz/column) -->

Lance Benner, private communication
November 21

Arecibo Images of 1996 FG3: 2011 Nov. 21, 0.5 usec x 0.24 Hz, 3 runs/frame

Doppler frequency (0.24 Hz/column) -->
Evidence for an equatorial ridge

1996 FG3: 2011 Nov. 22

Doppler frequency (0.24 Hz/column) -->

1999 KW4
What unique science can be achieved at 1996 FG3?

- **Binary system formation/life cycle**
  - 1996 FG3 is a close binary system, with a rapidly spinning primary, like 1999 KW4
  - Such systems are common in the NEO population

- **Asteroid surfaces with very low thermal inertia**
  - Lower than those for Eros or Itokawa

- **Preliminary detection of hydrated/hydroxylated minerals (unlike 1999 RQ36, the OSIRIS target)**

- **Possible spectral variation on surface**
  - Geographic diversity of material?
  - Linked to changing orbital position?
1996 FG3, one of two NEOs with 3µm band detection

A. S. Rivkin, private communication
1996 FG3: an unusual object

Very low thermal inertia

Unexplained spectral variation

Fig. 7: ATPM fits to the thermal-IR observations of 1996 FG3, assuming $f_i = 0.4$, which corresponds to the level of surface roughness measured on the Moon (Rozić & Green 2011). The different line styles correspond to different indicated levels of thermal inertia given in J m$^{-2}$ K$^{-1}$ s$^{1/2}$. Although mean fluxes are plotted for clarity, fits were to all the fluxes (error-weighted) as given in Table 4.

Wolters et al. 2011

De Leon et al. 2011
1. Rapidly spinning primary loses mass at equator, and close-in secondary reaccumulates

2. Scenario may explain unusual spin state and shape of primary in 1999 KW4 and similar systems

3. Dynamical evolution may be driven by the YORP/Yarkovsky thermal effects (which can unbind the binary; is this how 1999 RQ36 formed?)

4. Possible migration of regolith on the primary from poles to equator revealing fresh (previously subsurface) material on the poles (good candidate sites for unaltered sample collection?)

Left, numerical simulation of mass loss and reaccumulation (Michel et al. 2008); right, radar shape model of 1999 KW4 (Ostro et al. 2006)
Sample collection for MarcoPolo-R

(upper row) test of rock chipper and brush wheel in Bandelier tuff rock;
(lower row) simulation and test of brush wheel collecting lunar regolith simulant

[Proposed as NASA contribution]
Programmatic Framework

Launch
Apollo & Luna: 1969
Genesis: 2001
Stardust: 1999
Hayabusa: 2003
Phobos-Grunt: 2010
Hayabus: 2014
Osiris-Rex: 2016
MarcoPol: 2022
Return
1969
2004
2006
2010
2014
2020
2023
2029

Assessment Phase
Start Industrial Study
End Industrial Study
8 Nov. 2011
23 Nov. 2011
Feb. 2012
Spring 2013
Schedule

- Class M Missions: up to ca. 470 MEuro

Advisory structure

Selection of 4 missions

2011
- ESA-internal studies in Concurrent Design Facility

2012
- Industrial studies (2 competing for each mission)

2013
- Final presentation; selection of two missions for definition study

2013 - 2015
- Detailed definition study; selection of one mission

2015 - 2020
- Implementation phase in industry, launch 2020 - 2022