Near Earth Asteroid Sample Return

MARCO POLO
Near Earth Asteroid Sample Return Mission

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ESA study team: D. Koschny, D. Agnolon, J. Romstedt
International collaborations:

Community supporters:

658 scientists, 25 countries, and counting

JAXA junior participation (from Hayabusa heritage):

• GNC (Guidance, Navigation, and Control):
  ✓ Engineering supports by providing real data from Hayabusa for navigation training
  ✓ Hardware (e.g. LIDAR)
  ✓ From operations: determination of mass, shape, density, etc.

• Tracking support (e.g. ranging and telemetry)
• Heat shield of the Earth Re-Entry Capsule
• Outcomes of testing of sampling devices
• Science instruments

NASA junior participation:

SALMON (Stand Alone Missions of Opportunity):

hardware & software components
Marco Polo will rendezvous with a primitive NEA:
- scientifically characterize it at multiple scales, and
- return a sample to Earth unaffected by the atmospheric entry process or terrestrial contamination.

- Marco Polo is the first sample return mission to a primitive low albedo asteroid
- Marco Polo will return a sample (10s of grams) for laboratory analyses of organic-rich material
- Marco Polo will determine the geological context of the returned sample
Marco Polo addresses a wide range of objectives

Stars
Stellar nucleosynthesis
Nature of stellar condensate

The Interstellar Medium
IS grains, mantles & organics

The proto-solar nebula
Accretion disk environment, processes and timescales

Planetary formation
Inner Solar System Disk & planetesimal properties at the time of planet formation

Accretion history,
alteration processes,
impact events,
regolith

Life
Nature of organics in NEOs

The Earth
Impact hazard
Evolution of life on Earth
The Solar System formed from a disk of gas and dust orbiting around the Sun.
We need to return samples from space

Original material
Formation processes
Chronology

A pristine sample from a primitive asteroid is required to study the precursors of terrestrial planets
Look different, but common origin
Look different, but common origin.
Only primitive types retain a memory of the origin.
Near Earth Asteroid Sample Return

Marco Polo target:
dark primitive classes: C, P, D
Near Earth Asteroid Sample Return

Planetary Formation

- Eucrites Differentiation
- HED differentiation
- Planetesimal accretion
- Mars
- Earth

CAIs

Chondrules

Angrites

Mesosiderites

Pallasites

Angrites

CAIs

D

IC

4558

4568

Absolute Time Before Present (Myr)
Asteroid population

Near Earth Asteroids
More than 6000 known NEOs
Fast resonances: Main Belt Asteroids become rapidly NEAs by dynamical transport from a source region (in a few million years).

Animation showing evolution of asteroid orbits.
Why an NEA?

NEAs offer many advantages:

- Accessibility
- Identified links to the origin population
- Great diversity of physical properties composition
- Hazard mitigation

1999 JU3: C class, 0.92 km

NEA ACCESSIBILITY H- PLOT

1999JU3
1999UQ
Eros
Itokawa
2001SG286
2001SK162
ASTEROID MAIN BELT
NEA POPULATION (H<21)
NEAs visited
Marco Polo targets
Marco Polo will provide crucial elements to answer the following key questions:

1) What were the processes occurring in the primitive 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?
What were the processes occurring in the early solar system and accompanying planet formation?

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

Measurements

Bulk chemistry
Mineralogy, Petrology
Isotopic chemistry in inclusions, matrix, presolar grains and volatiles, water
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

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 IDPs and provide ground truth for the astronomical database

Measurements

- Volume, shape, mass
- Surface morphology and geology
- Mineralogy & Petrology
- Isotope geochemistry & chronology
- Weathering effects

Composite Spectra of Eros

Gravitational Map (Model-A)
Do NEAs of primitive classes contain pre-solar material yet unknown in meteoritic samples?

Meteorites contain refractory pre-solar grains from supernovae, novae, AGB stars.

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

Measurements

- Bulk chemistry
- Grain mineralogy and composition
- Isotope chemistry of grains
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?

Current exobiological scenarios for the origin of life invoke the exogenous delivery of organic matter to the early Earth.

The planets of the inner solar system experienced an intense influx of organic-rich material for several hundred million years after they formed. The earliest evidence for life on Earth coincides with the decline of this bombardment.

Many biologically important molecules are present in the organic materials.
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?

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

Measurements

Abundances and distribution of insoluble organic species
Soluble organics
Global surface distribution and identification of organics
Near Earth Asteroid Sample Return

From stars to meteorites

after Davidson 2009
From stars to meteorites

Nucleosynthesis

Condensation

Implantation

Accretion

Thermal/aqueous alteration

Impacts

Weathering

Atmospheric entry

Contamination weathering

Mantle formation

Chemical reaction

Shock

Irradiation

Evaporation

Condensation

Shock

Irradiation

Chemical reaction

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after Davidson 2009
“Why do you need to return samples?”
Superior instruments...

“Miranda” GC-IRMS Laboratory
Isotope ratio ± 0.01%

In-situ instruments limited  (mass/volume/power/reliability)
Superior instruments…

Diamond synchrotron source
In-situ measurements provide insufficient precision

Whole-rock measurements

Meteorites
- CI,CM
- CO,CV,CK
- Enstatite
- Ordinary
- SNC
- Basaltic Achondrites
- Ureilite

Grady, 2004
In-situ measurements provide little or no sample discrimination.
Complexity...

- Same sample analysed by many instruments
- Complex sample selection and preparation

Example: isotope dating of chondritic components

Context (mm–µm) – check secondary effects

Initial selection

Split

Process characterisation

Isotope dating
- Dissolution
- Purification
- Analysis
- Calibration

Near Earth Asteroid
Sample Return

Zega et al 2007

Fehr

Krot

Initial selection

Split

Isotope dating
- Dissolution
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Near Earth Asteroid
Sample Return

Zega et al 2007

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Zega et al 2007
“Why do you need to return samples when we have meteorites?”
To survive atmospheric entry requires major processing.
Pre-solar grains

Many sources, and stellar environments

After Davidson 2009 unpublished

Aqueous Alteration

Pre-solar Silicate Abundance

SiC
Silicate
nDiamond
Spinel
Graphite

Pre-solar Silicate Abundance

28Si  44Ti
Aqueous alteration

Mixed regolith provides range of alteration
Free of terrestrial contamination
→ find low alteration materials
→ study alteration process

Water
Carbonaceous chondrites exhibit aqueous alteration
- How much water was there initially?
- What was the fate of the water?
- Implications for terrestrial planets.

Is D/H in primitive asteroids similar to that on Earth?
Avoid contamination…

Tagish Lake
Most perfectly collected sample?

Collected within 5 days from frozen lake and kept at -20°C

→ terrestrial contamination

… any result obtained for organics in meteorites may be questioned
Organics

Over 80 ET amino acids

Many different synthesis mechanisms

Strecker

Hydrolysis

Ammonia addition

Requires precise abundances of molecules and precursors
**Context**

**Marco Polo payload:**
- Structure (shape, density)
- Collisional history
- Cratering record
- Geological context
- Compositional heterogeneity
- Space weathering

**Laboratory data:**
- Petrology, composition, chronology

Meteorite/NEA spectra/ground truth
NEA sample return will use a combination of in situ and laboratory measurements to

- provide a unique window into the distant past
- allow scientists to unravel mysteries surrounding the birth and evolution of the solar system
- involve a large community, in a wide range of disciplines
  - Planetology
  - Astrobiology
  - Nucleosynthesis
  - Cosmochemistry
- retain samples for future advances through a Curation and Distribution Facility
- demonstrate key capabilities for any sample return mission
- generate tremendous public interest
Mission profile

- 6 year mission to 1999 JU₃ (17 months at the asteroid)
- Direct escape, single spacecraft (chemical) + Earth re-entry capsule
- Launch mass: ~1450 – 1560kg
- Total delta-V ~ 1600 m·s⁻¹
- Re-entry velocity ~ 12 km·s⁻¹
- Earth-Spacecraft: 2.4 AU max.
- Sun-Spacecraft: 0.85 – 1.55 AU
- Asteroid properties
  - Diameter ~ 1 km
  - Rotation period: 7.7 hours
Baseline payload

Wide angle camera
Narrow angle camera
Close-up camera
Vis/NIR imaging spectrometer (0.4–3.3 µm)
MIR spectrometer (5–25 µm)
Radio science
Laser altimeter
Neutral particle analyser
Complementary instruments/lander possible

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<th>Total</th>
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<tr>
<td>Mass [kg]</td>
<td>30</td>
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<tr>
<td>Power [W]</td>
<td>90</td>
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<tr>
<td>Data volume [Gbit]</td>
<td>280</td>
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Development compatible with overall schedule
Descent/Sampling

Landing/touchdown
- 3 sampling attempt capability
- Clearance: ~ 50 cm hazards
- Landing accuracy ~ 5 m

Sampling
- Dust to cm-sized fragments
- Contamination-avoidance strategy

Asteroid descent and sampling sequence
Descent/Sampling

1. Asteroid characterization
2. Hovering at 200 – 400 m altitude, “go-decision”
3. Autonomous terrain-relative descent
   • Navigation camera + multi-beam laser/radar altimeter
4. Touchdown/sampling
5. Ascent to safe position

Asteroid descent and sampling sequence

Example of touchdown operation
Descent/Sampling

- **Sampling option 1**: Short-term landing (~ 10 min.), “energy-absorbing” landing legs, down-thrust, rotating corer (sample canister)

- **Sampling option 2**: Touch & go (< 3 sec.), “elastic” legs, fast sampler (sample canister)
Main spacecraft

**Concept 1:** Corer, top-mounted capsule, one articulated arm inside central cylinder

**Span:** 8m  
**Height:** ~ 2.5m

**Concept 2:** Corer, bottom-mounted capsule, two articulated arms

**Concept 3:** Fast sampler, top-mounted capsule, transfer via landing pads/legs + elevator in central cone
1. $T_0 - 4$ hours: Separation with main spacecraft
2. $T_0$: Re-entry (heat flux $\sim 15$ MW·m$^{-2}$)
3. $T_0 + 200$ s: Parachute opening ($\sim 10$ km, subsonic)
4. $T_0 + 1800$ s: Soft landing in Woomera, Australia
5. Landing + few min/hrs: Search & Recovery
Earth re-entry capsule

- 45° half-cone angle front shield
- In-development lightweight ablative material or classical carbon phenolic
- Capsule mass: 25 – 69 kg
Development

- Proto-Flight Model + dedicated qualification models
- No specific planetary protection measures required
- Pre-development
  - Sample acquisition, transfer and containment system
  - Guidance, Navigation & Control (GNC) – descent/sampling
  - Further development of ablative material
  - Low-gravity landing/touchdown system
- All testing facilities available
ESA review: risk items

- GNC development beyond ESA’s state-of-the-art: potential schedule driver + performance uncertainty
  - Landing accuracy can be relaxed to ~ tens of metres

- Further consolidation of sample soil properties
- Higher risk associated to touch & go, early selection of short-term landing recommended
## Conclusions

- **Technically feasible mission**
- Maximal use of ongoing/past activities allows an effective and robust development plan
  - Safe landing/touchdown (including “relaxed” GNC)
  - Sample collection, transfer and sealing
  - Earth re-entry
- **High heritage and no pre-development needed for:**
  - Mission and science operations
  - “Standard” platform equipment (e.g. power, thermal, propulsion)

### Marco Polo spacecraft mass budget (kg)

<table>
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<th>Contractor 1</th>
<th>Contractor 2</th>
<th>Contractor 3</th>
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<tbody>
<tr>
<td>Total dry mass</td>
<td>745</td>
<td>744</td>
<td>812</td>
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<tr>
<td>Launch mass</td>
<td>1448</td>
<td>1462</td>
<td>1557</td>
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<tr>
<td>Launch vehicle performance</td>
<td>1629</td>
<td>1719</td>
<td>1629</td>
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<tr>
<td>Launch mass margins (%)</td>
<td>11</td>
<td>15</td>
<td>4</td>
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