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Lutetia/ESA

NASA

M. Champenois
MarcoPolo-R addresses the scientific questions:

1) What are the conditions for life and planetary formation?

2) How does the Solar System work?

Related issue with a Near-Earth Asteroid characterization:

- Impact hazard and mitigation
MarcoPolo-R will:

- Return ~100g of sample for high precision lab analysis
- Characterize a primitive Near-Earth Asteroid at multiple scales
Formation & Evolution of the Solar System

Hubble Space Telescope Orion Treasury Project Team

Beta Pictoris, European Southern Observatory
Formation & Evolution of the Solar System

Proto Sun

Protoplanetary Disk

Dust + Gas

Planetesimals

Planet Formation and Migration

The Solar System today

The Solar System today

Courtesy: S. Tachibana
Formation & Evolution of the Solar System

Proto Sun

Protoplanetary Disk

Dust + Gas

Planetesimals

Small primitive bodies:
- record complex chemical and physical processes in the early Solar System

Large evolved bodies:
- melting & differentiation

Planet Formation and Migration

The Solar System today

Courtesy: S. Tachibana
Why sample return?

Stadermann et al., 2010

ESRF synchrotron facility

Adaptability

Environmental control

Spatial resolution

ESRF synchrotron facility

High energy

Precision
Sample return legacy

Apollo NASA
Luna Soviet Union
Origin of the Moon
Accretion of planets

Stardust NASA
Comet composition
Large scale mixing

Genesis NASA
Isotopic composition of the Sun

Hayabusa JAXA first sample returned from (evolved S-type) asteroid

Credits: NASA & JAXA
European cosmochemistry

European teams at the forefront of sample return analysis

- Cosmochemistry: a science born in Europe
- Genesis: 2 of 4 scientific goals done by European labs
- Stardust: 1/3 labs were European in the Preliminary Examination Team

Analytical instruments used worldwide for ET samples designed and made in Europe

- Cameca (F): ion probes
- Nu Instruments (GB): mass spec.
- Thermofisher (D): mass spec.
The next two decades: exploration of asteroids

- MarcoPolo-R will sample an unexplored region of the disk
- Prepare for human exploration of the Solar System

Returning this sample will keep Europe at the forefront of planetary science
The next two decades: exploration of asteroids

Hayabusa2
JAXA

OSIRIS-REx
NASA

MarcoPolo-R
ESA

1+1+1 >> 3!

NASA committed to provide substantial contributions
JAXA expressed interest

Returning this sample will keep Europe at the forefront of planetary science
1. What was the *astrophysical setting* of the birth of the Solar System?

2. What is the *origin and evolution* of material in the early Solar System?

3. What are the *physical properties* and evolution of the building blocks of terrestrial planets?

4. How do *volatiles and organics* in primitive NEAs relate to the atmosphere and life on Earth?
1. What was the astrophysical setting of the birth of the Solar System?
Fine–grained matrix hosting organics, volatiles

Low temperature fine grained matrix

Eros, NEAR (NASA/JHU/APL)
Fine–grained matrix hosting organics, volatiles

Photo: H. Leroux
Fine–grained matrix host grains of non-solar composition

Presolar graphite
2 nanometer scale transmission electron microscope image

SiC grains

Presolar diamond

Corundum

Credit: Univ. Chicago, MPI Mainz, Carnegie Inst. Wash
Pre-solar grains that survived Solar System formation

Presolar graphite
Presolar diamond
2 nanometer scale transmission electron microscope image

SiC grains
Corundum

Credit: Univ; Chicago, MPI Mainz, Carnegie Inst. Wash
Insights into stellar nucleosynthesis

Presolar grains provide information about nucleosynthesis and stellar evolution

- Isotopic signatures of rapid neutron and alpha captures
  - testing models of supernovae explosions (eg, $^{44}$Ca)
- Insight into galactic evolution (eg AGB stars)
- Physico-chemical conditions and events in stellar envelopes (eg red giants)
What are the links between past stars and the Solar System?

- Supernova
- AGB Star
- Molecular Cloud
- Proto-planetary disk
- Primitive asteroids
- Lab analysis

NASA, NEAR
2. What is the origin and evolution of material in the early Solar System

Ca-Al-rich inclusions (CAI)
(10 µm - 2 cm)

Eros, NEAR (NASA/JHU/APL)
Extinct radioactivities: key tracers of early Solar System events

$^{26}\text{Al} \rightarrow ^{26}\text{Mg} \left( T_{1/2} = 0.7 \text{ Ma} \right)$

$^{60}\text{Fe} \rightarrow ^{60}\text{Ni} \left( T_{1/2} = 2.4 \text{ Ma} \right)$

NGC 6357, Hester & Desch (2005)
Extinct radioactivities: key tracers of proto-solar events

Timing of Supernova explosions?
Radioisotope systems are susceptible to resetting during meteorite forming process

Samples of primitive unaltered material should significantly improve chronology
3. What are the physical properties and evolution of the building blocks of terrestrial planets?

Regolith: the lunar soil legacy

Eros, NEAR (NASA/JHU/APL)
A world in a grain: investigating asteroid processing in dust

- Cosmic-ray produced
- Indigenous Volatiles (?)
- Radiogenic production
- Amorphized skin

0.5 µm

Solar wind
Non SW, surface-correlated

Photo: Y. Langevin

NASA
A world in a grain: investigating asteroid processing in dust

Apollo soil grain 79035, 1 Ga

Hashizume et al., 2000
4a. How do organics in primitive NEAs relate to life on Earth?

The origin of life on Earth remains one of humankind’s important unanswered questions.

Organics from space

Extraterrestrial delivery via small bodies seeded the young Earth during its early history: precursor material for life?
Insights into cosmic carbon chemistry

Interstellar and circumstellar regions:
~ 180 molecules are detected and many carbon allotropes.

Carbonaceous meteorites contain:
macromolecular carbon, biomolecules, hydrocarbons, nanoglobules...

MarcoPolo-R will permit analysis of a unique sample of abiotic organic chemistry as it was in the Solar System shortly before the onset of life.
4b. How do volatiles (H, C, N...) in primitive NEAs relate to the atmosphere and oceans on Earth?

• What are the compositions of asteroids? Only measurements are from meteorites – possibility of terrestrial contamination
• Are comets/asteroids the origin of terrestrial water and atmosphere?
A comet-asteroid continuum?

The computed water/rock ratio in meteorites (representative of asteroids?) is up to 1 (Clayton 1984, Young et al. 2002)

The observed water/rock ratio of Comet Tempel 1 is 1 (A’Hearn et al. 2005)

What is the difference between a water-rich asteroid & a dust-rich comet?
Why do we need to return samples when we have meteorites? Atmospheric entry

More than 99% of material lost in the atmosphere; only the <1% strongest survives.

Carbonaceous chondrites are under-represented on Earth (5%) compared to the abundance of carbonaceous-type asteroids.

Explosion of a cometary particle in Stardust aerogel.
Why do we need to return samples when we have meteorites? Terrestrial contamination.

Chelyabinsk: a fresh fall!
Why do we need to return samples when we have meteorites?

Tagish Lake
Most perfectly collected meteorite to date?

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

→ terrestrial contamination

... results obtained for organics in meteorites may be questioned
MarcoPolo-R will:

• Return ~100g of sample for high precision lab analysis

• Characterize a primitive Near-Earth Asteroid at multiple scales
Where to take a sample from an asteroid?

Grand-Tack scenario: the asteroid belt contains primitive material formed in the outer Solar System (Walsh et al. 2011)

$T(\text{kyr}) = 0$ is 600 kyr before the end of the gas phase of the disk. Jupiter is formed, Saturn is still growing.
Where to take a sample from an asteroid?

Grand-Tack scenario: the asteroid belt contains primitive material formed in the outer Solar System (Walsh et al. 2011)
Where to take a sample from an asteroid?

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Where to take a sample from an asteroid?

Grand-Tack scenario: the asteroid belt contains primitive material formed in the outer Solar System (Walsh et al. 2011)

Material originally formed beyond Saturn

Material originally formed between Sun and Jupiter

T (ky) = 600
Where to take a sample from an asteroid?

From numerical simulations of asteroid disruptions:
Most small asteroids (>200 m and < 100 km) are rubble piles
Michel et al. 2001, 2003

Collisions, rubble piles, and dynamical instabilities: most NEAs comes from the main belt via well identified dynamical mechanisms (resonances)
Why a NEA?

- NEAs are the most accessible targets for primitive material sample return
Why a NEA?

- NEAs are the most accessible targets for primitive material sample return.
- Some NEAs are potentially hazardous.
Impacts have both beneficial and destructive effects on the evolution of planetary biospheres.

Explosion over Chelyabinsk on 15 Feb. 2013 (17 m-size object)

Meteor Crater (Arizona)
Up to 100 m class object
Age ~50,000 years

Mitigation strategies need better knowledge of NEA properties
Small body populations

A wide variety of physical & compositional properties

- 243 Ida
- 2867 Steins
- 9969 Braille
- 5535 Annefrank
- 433 Eros
- 25143 Itokawa
- 253 Mathilde
- 951 Gaspra
- 21 Lutetia
- 19P/Borrelly
- 9P/Tempel 1
- 81P/Wild 2
- 103P/Hartley 2
- 1P/Halley

100 km
Small body populations

A wide variety of physical & compositional properties

Eros (NEAR)

D~17 km, S-type

©NASA
Small body populations

A wide variety of physical & compositional properties

Dactyl

243 Ida

Itokawa (Hayabusa)

D~320 m, S-type

253 Mathilde

951 Gaspra

21 Lutetia

19P/Borrelly

9P/Tempel 1

103P/Hartley 2

1P/Halley

81P/Wild 2

We do not have yet detailed information on a primitive NEA

©JAXA
The attractive NEA 2008 EV5
(Potentially Hazardous Asteroid)

Orbit close to that of the Earth
The attractive NEA 2008 EV5
(Potentially Hazardous Asteroid)

Known dynamical and physical properties:

- Simple and short mission: 4.5 years in total with launches in 2022-2023
- Substantially simplifies the overall mission (e.g. propulsion, asteroid operations and GNC, power, thermal control, communications)
400 ± 50 metre oblate spheroid

Period = 3.725±0.001h

Albedo: 0.10-0.12

No evident large blocks (at 7.5 m-resolution)

Busch et al. 2011
2008 EV5 has a top shape, a ridge and a rotation period similar to that of binary’s primaries.

Binary 1999 KW$_4$ radar model, Ostro et al. 2005

Binary 2004 DC
Taylor et al. 2008, ACM

Single 2008EV5
Busch et al. 2011

YORP spinup sims, Walsh et al. 2008
Unique science value of 2008 EV5

- Spectral type: belongs to the C complex

0.48-µm absorption band indicative of aqueous alteration

Parent body likely accreted in an unfractionated volatile rich region

Reddy et al. 2012
Unique science value of 2008 EV5

MP-R will allow us to access information on the conditions of accretion in distant regions of the Solar System.

CI meteorite Orgueil

Elemental composition identical to the Sun (except for the most volatile elements)

Meteorite richer in:
- water 20%
- organic matter 5%
- Contains amino acids

Abundance CI chondrite

Lodders 2003

Parent body likely accreted in an unfractionated volatile rich region
Clarifying the asteroid-comet continuum

Active asteroids have been identified in the main asteroid belt

- Outgassing from Ceres has been detected by Herschel Space Observatory (Kueppers et al., 2014)

- Albedo of Ceres = 0.10 similar to 2008 EV5!

EV5 may be a transitional object
Formation of 2008 EV5

Disruption of a parent body and reaccumulations

Parent Body
- Heavily altered
- Moderately altered
- Unaltered primitive material

NEA

A NEA contains parent components that do not survive atmospheric entry

Regolith is a mixture of some or all components

Michel & Richardson 2013

JAXA
Thermal Inertia $\Gamma$ of $\approx 450 \pm 100$ J s$^{-1/2}$ K$^{-1}$ m$^{-2}$

Average grain size of the regolith may be of the order of 0.5 - 1 cm

Delbo et al. 2013

Current mean distance to the Sun remains close to 1 AU: prevents high temperature excursions

The maximum temperature is up to 40 K lower at 1 cm depth
2008 EV5
An ideal target for sample return

- It provides for the most exciting science, with signatures suggesting an unfractionated, volatile rich body.

- It is a primitive asteroid with a moderate albedo, a class of object (possibly transitional to comets?) never visited before by a spacecraft.

- Study of a Potentially Hazardous Asteroid is strategically important to space agencies and international institutions concerned with hazard and mitigation.

Busch et al. 2011
2008 EV5 rises to the top of the asteroid charts!

- 1 asteroid with albedo ~0.10-0.12 (from a distinct primitive population)
- 2 asteroids with albedo < 0.06 to be sampled by OSIRIS-REx (NASA) and Hayabusa 2 (JAXA)
- ~5 carbonaceous/primitive ones
- ~350 accessible for sample return
- ~10000 Near Earth Asteroids
Mission scenario

**Operations overview**

- Soyuz-Fregat launch
- Direct escape
- 1700 kg launch mass

1700 kg launch mass

Transfer to asteroid via electric propulsion
1 Earth fly-by

6-month operations:
- asteroid characterization
- Touchdown/sampling

December 2022

Soyuz-Fregat launch
Direct escape
1700 kg launch mass

Backup in Dec 2023, Dec 2024

January – July 2025

Earth re-entry and landing in Australia

June 2027

Launch windows as early as 2022; full mission duration: 4.5 years
Science payload

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- Map the global properties, chemistry, and mineralogy to characterize the geologic and dynamic history
- Allows selection of the sampling site and provides context for the returned samples
- Low-risk payload:
  - Total 33 kg, incl. all margins
  - Well-known design and operations

JAXA proposed contribution: a LIDAR as a support of GNC
Science payload

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JAXA proposed contribution: a LIDAR as a support of GNC
Sampling tool development

Top-level requirements:

- Get > 100 g sample in 3-5 seconds
- Compatible with a range of soil properties

Parallel sampling tool developments

- Brush-wheel at AVS, Spain
- Grab bucket at Selex-ES, Italy

NASA funded study to MarcoPolo-R

- Includes:
  - Enhanced sampling tool with a rock chipper to deal with consolidated rocks

http://us-marcopolor.jhuapl.edu
Earth Re-entry Capsule and recovery

- Fully passive capsule, ~ 500 s re-entry
- Landing ellipse knowledge ~ a few km
- Safest and lowest cost approach

Heat shield prototype (Astrium Ltd)

Re-entry at 12 km/s at dawn
Re-entry observations

~50 km

Woomera desert (Australia)

Coober Pedy

~35 km

Tarcoola

LW2022

LW2024

Technologies

- Sample return from an asteroid is now feasible in Europe
- Major progress achieved in Europe in the last few years, e.g.:
  - Heat shield material technology
  - Sampling tool
  - Asteroid descent and touchdown guidance, navigation and control
Curation Facility

Samples rapidly transferred to a curation facility

- Canister opened in ultraclean environment
- Preliminary examination phase by a selected team
- Distribution to the community at large – Independent allocation committee
- Archiving for future generations
Asteroid sample return missions generate a tremendous public interest

MarcoPolo-R comics book
Translations in English, French, German, Italian, Spanish, Portuguese, Greek, Russian, Chinese

MarcoPolo-R is on Facebook
Asteroid sample return missions generate a tremendous public interest.

MarcoPolo-R comics book
Translations in English, French, German, Italian, Spanish, Portuguese, Greek, Russian, Chinese

MarcoPolo-R is on Facebook

A pacifier for future scientists! (found on internet)
A new ERA of Sample Return

- MarcoPolo-R
  - Distinct information about our Solar System history in a timely manner
  - Development of a European curation facility and accompanying expertise for future sample return endeavours
Why MarcoPolo-R?

• Allows us to unravel mysteries surrounding the birth and evolution of our Solar System

• Provides major breakthroughs in how organics in primitive NEAs relate to the origin of life on Earth

• Is relevant to a wide range of science fields
  Astrophysics, Astrobiology, Cosmochemistry, Planetology, Impact Hazard Mitigation

• Provides invaluable samples for generations of scientists decades after its return

• Technology, industrial and outreach return
Why now?

- Technically feasible mission with short duration, within M-class:
  4.5 years with launch opportunities from 2022 to 2024

- For Europe:
  - Contribution in a very timely and significant manner to the international sample return effort
  - Defines its position at the frontier of future sample return endeavours

A UNIQUE asteroid target accessible in 2022 – 2024: the most scientifically valuable and affordable Sample Return Mission for Europe in the next 2 decades

http://www.oca.eu/MarcoPolo-R/