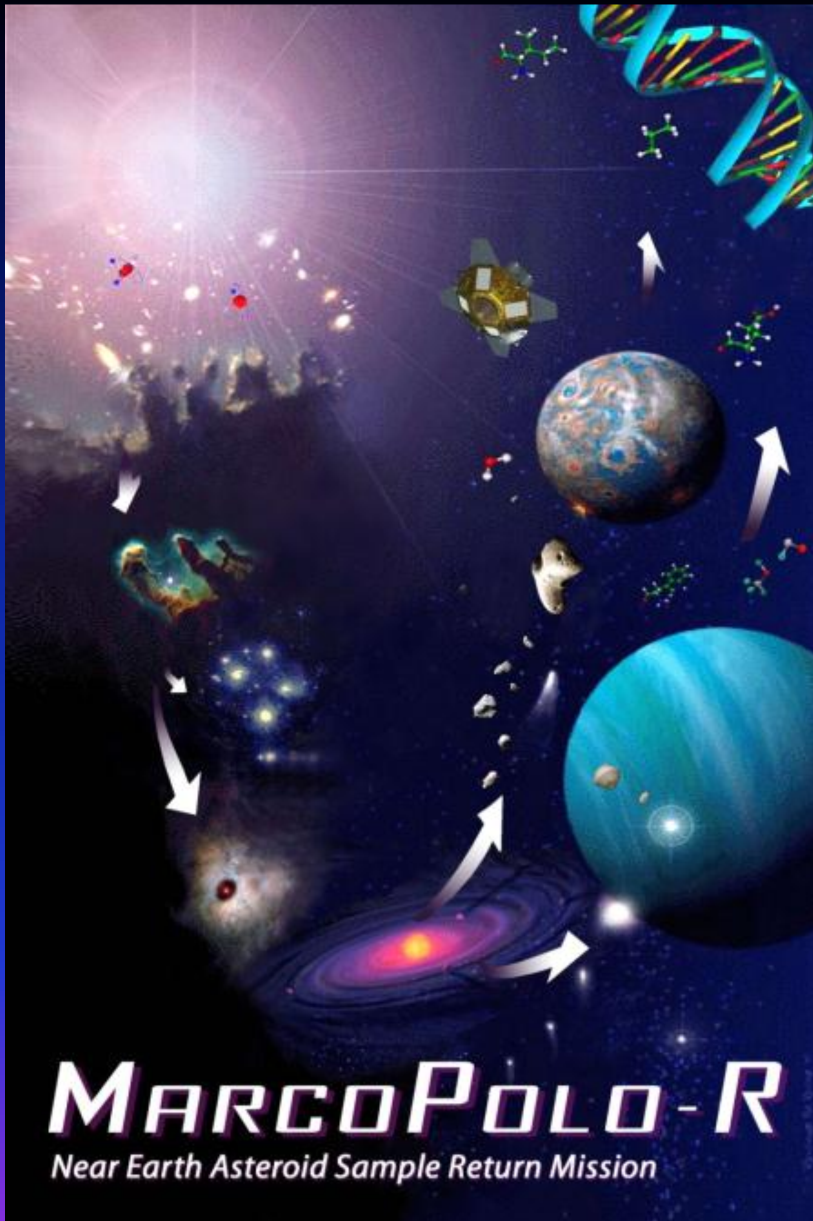


Selected in Feb. 2011 for assessment study phase
Next selection step: ~~June~~ Dec. 2013

Cosmic Vision ESA – M3

Science Study Team (SST):

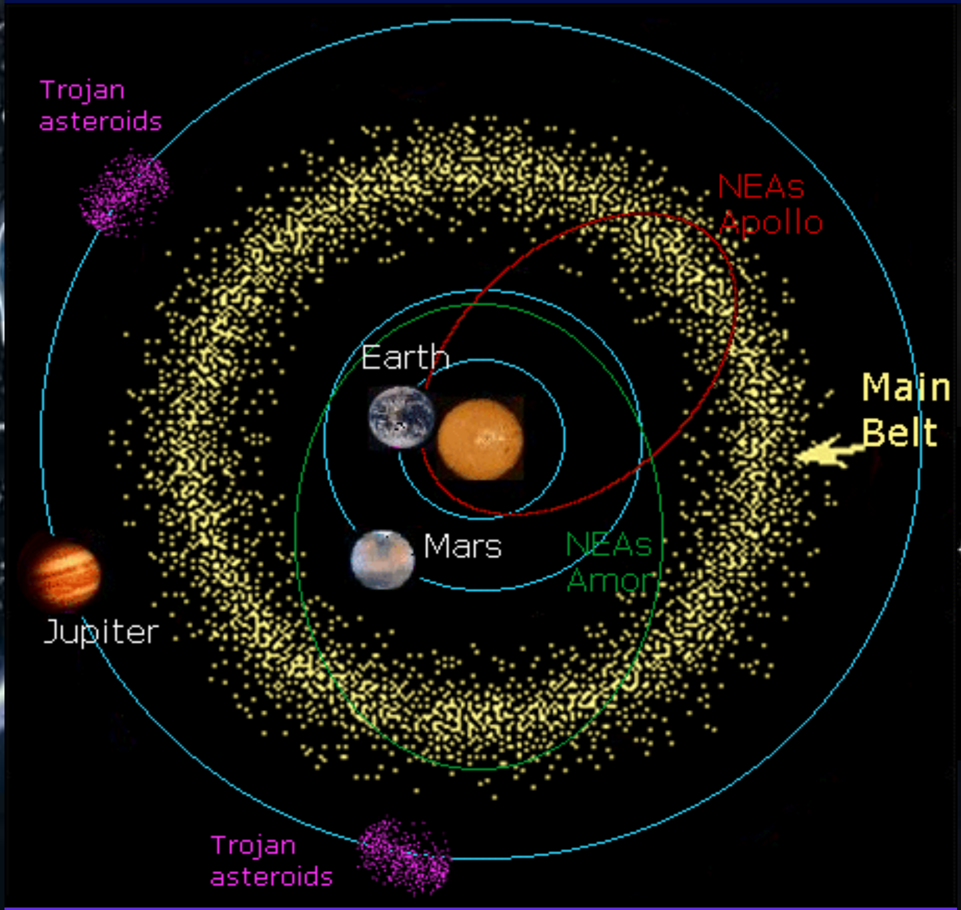
M.A. Barucci (F) Chair
P. Michel (F) Co-Chair
J. Brucato (I)
H. Böhnhardt (D)
E. Dotto (I)
P. Ehrenfreund (NL)
I. Franchi (UK)
S. Green (UK)
L. Lara (E)
B. Marty (F)

Detlef Koschny
(ESA - Study Scientist)

David Agnolon
(ESA- Study Manager)

Jens Romstedt
(ESA - Study Payload Manager)

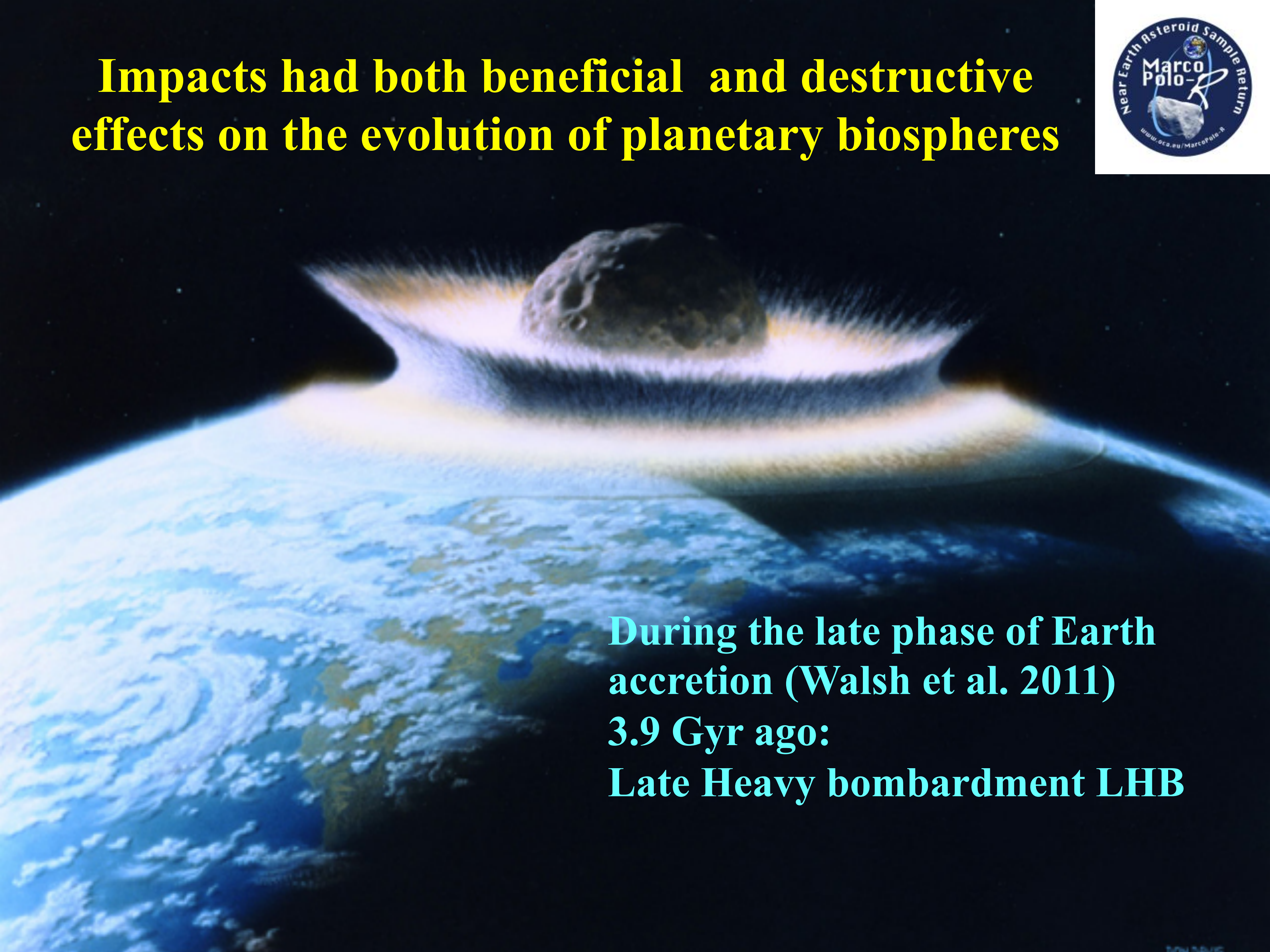
Small bodies in our Solar System



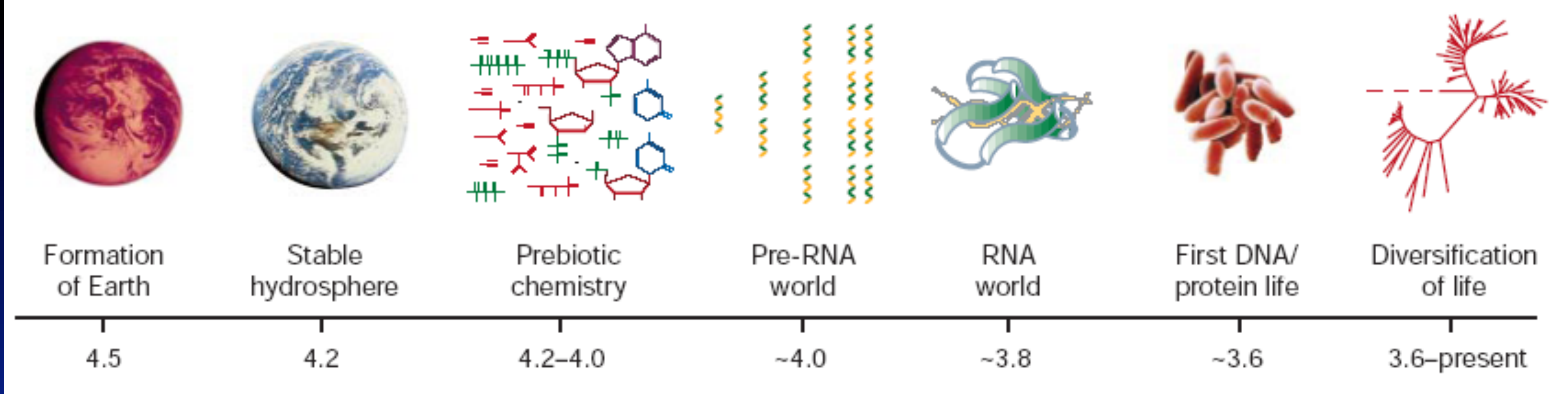
- Several populations: Near-Earth, main belt, Kuiper belt
- Fate: impact into the Sun, on planets, ejected from the Solar System

Tracing the origins …

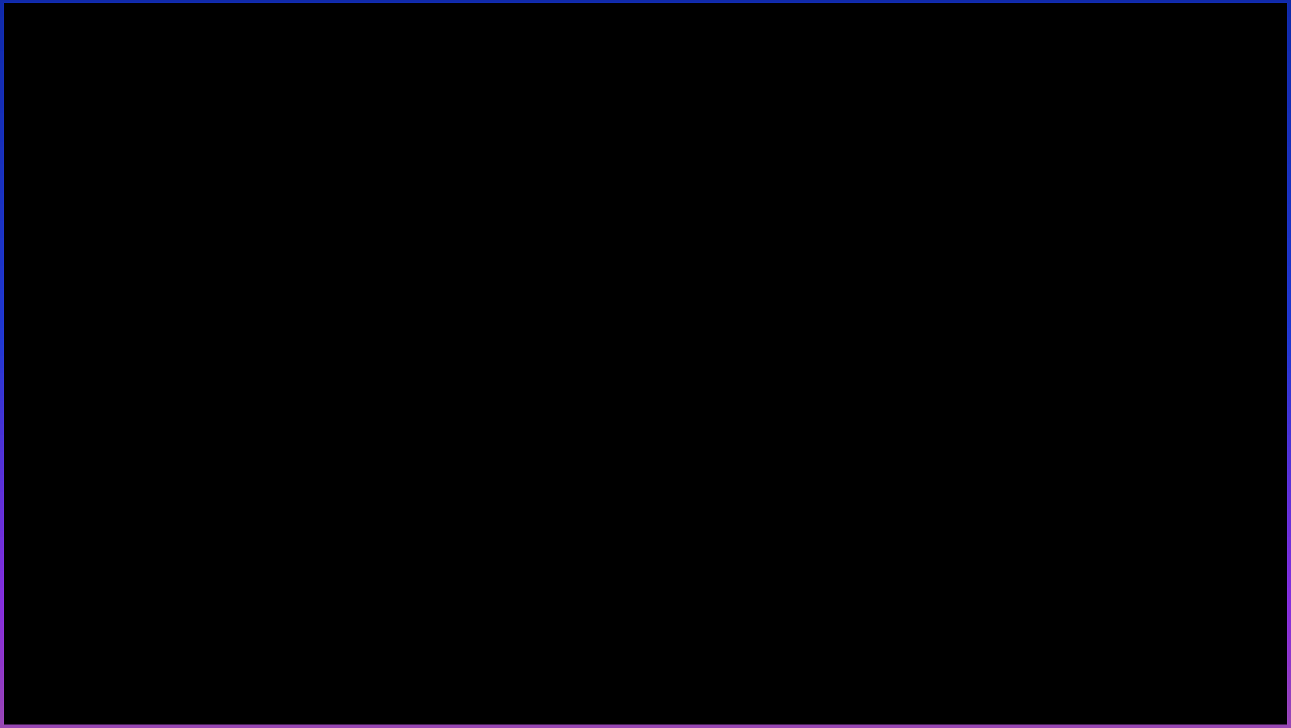
Impacts had both beneficial and destructive effects on the evolution of planetary biospheres



During the late phase of Earth accretion (Walsh et al. 2011)
3.9 Gyr ago:
Late Heavy bombardment LHB



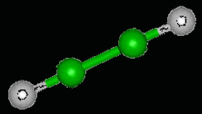
Current exobiological scenarios for the origin of life invoke the exogenous delivery of organic matter to the early Earth



The planets of the inner solar system experienced an intense influx of organic-rich material for several hundred million years after they formed.

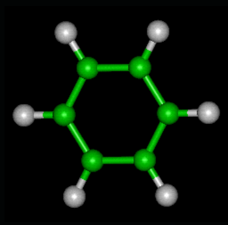
The earliest evidence for life on Earth coincides with the decline of this bombardment.

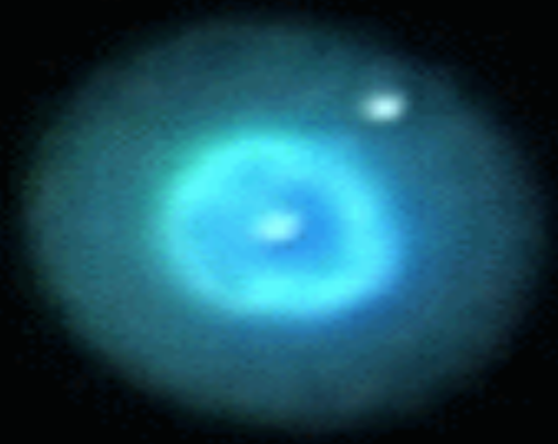
Many biologically important molecules are present in the organic materials.

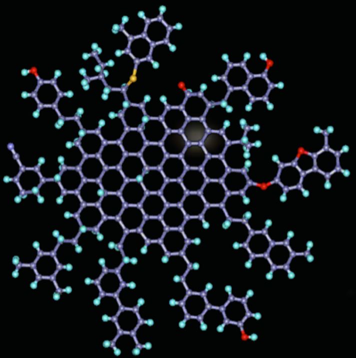


Carbon chemistry

From stars to life

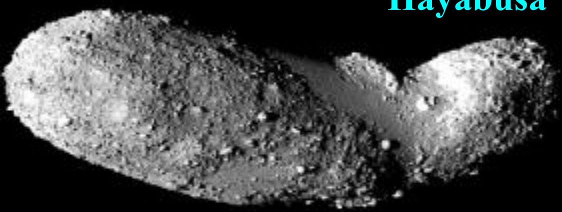




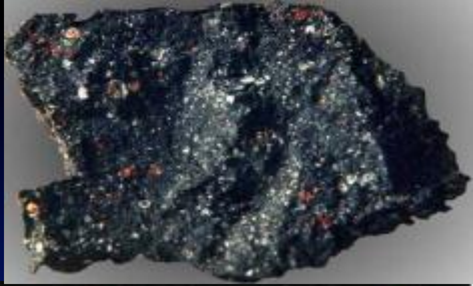


Stardust

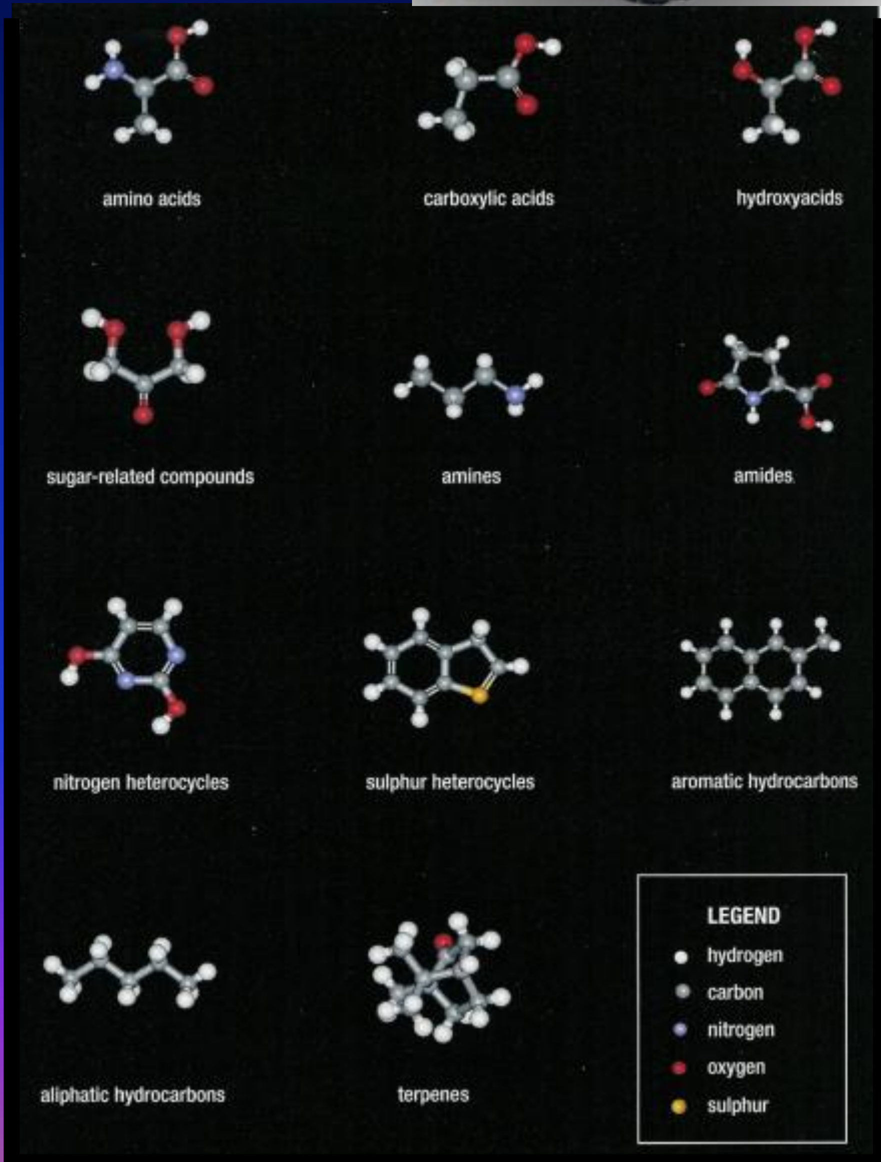
Hayabusa



Organic compounds in Murchison

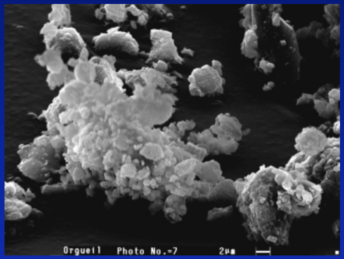


Compound Class	Concentration(ppm)
CO_2	106
CO	0.06
CH_4	0.14
NH_3	19
Aliphatic hydrocarbons	12-35
Aromatic hydrocarbons	15-28
Amino Acids	60
Monocarboxylic acids	332
Dicarboxylic acids	26
a-hydroxycarboxylic acids	14
Polyols (sugar-related)	~24
Basic N-heterocycles	0.05-0.5
Purines	1.2
Pyrimidines	0.06
Amines	8
Urea	25
Benzothiophenes	0.3
Alcohols	11
Aldehydes	11
Ketones	16



Sephton 2002

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?



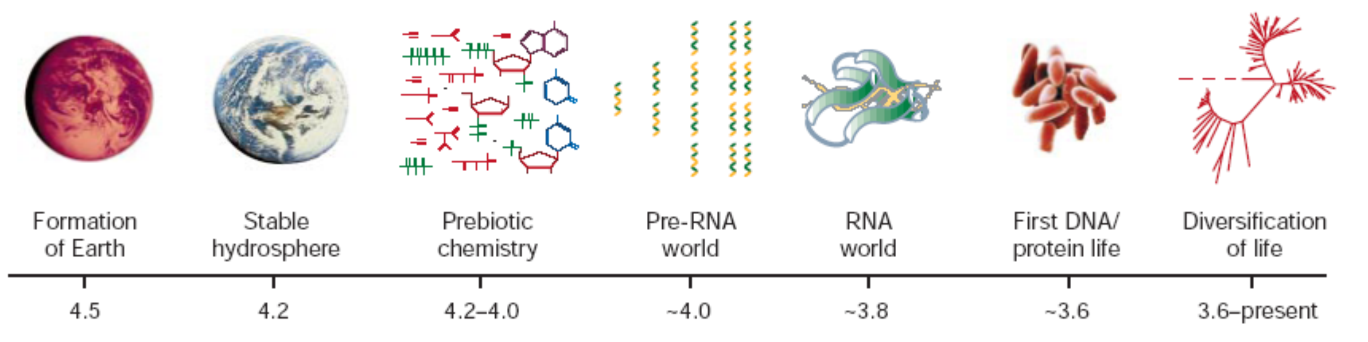
K. Determine the diversity and complexity of organic species in a primitive asteroid

L. Understand the origin of organic species

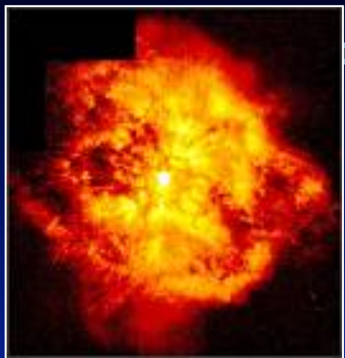
M. Provide insight into the role of organics in life formation

Measurements

Abundances and distribution of insoluble organic species
Soluble organics
Global surface distribution and identification of organics



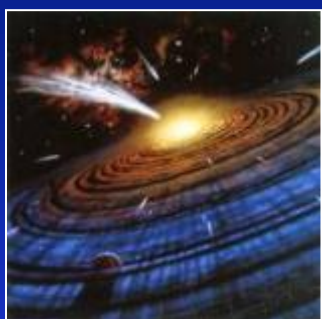
MarcoPolo-R addresses a wide range of objectives



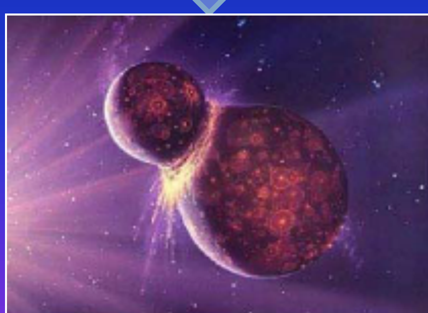
Stars
Stellar nucleosynthesis
Nature of stellar condensate grains

The Interstellar Medium
IS grains, mantles & organics

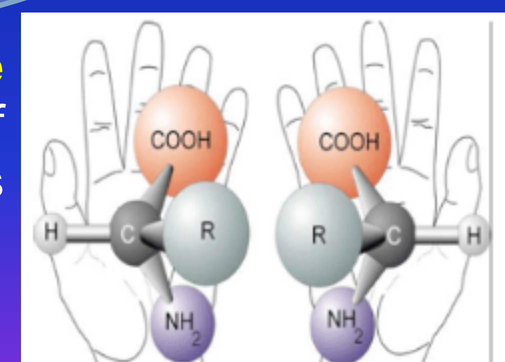
The proto-solar nebula
Accretion disk environment,
processes and timescales



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



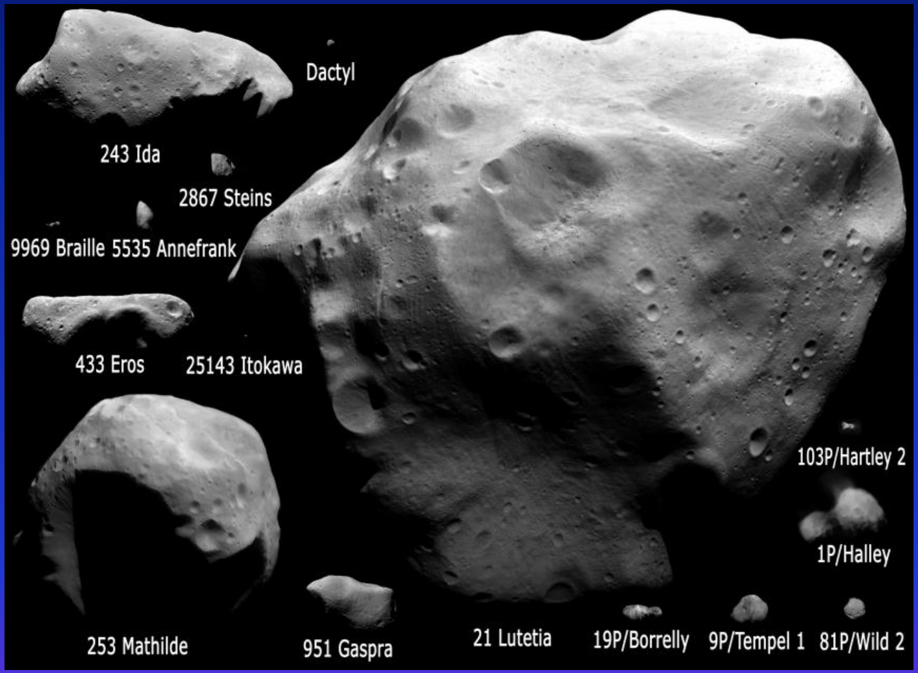
Asteroids
Accretion history,
alteration processes,
impact events,
regolith

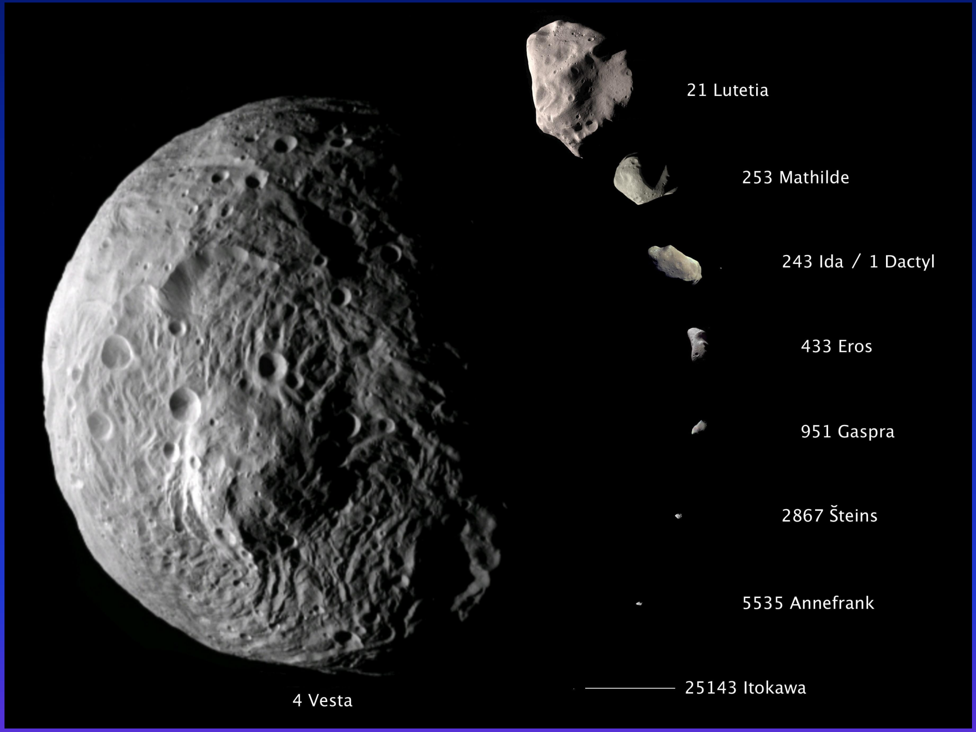


Life
Nature of
organics in NEOs

The Earth
Impact hazard
Evolution of life on Earth

Asteroids: a wide variety of physical & compositional properties





~100 km

~500 km

We do not have yet a detailed image of a primitive Near-Earth Asteroid
We need several missions to obtain a comprehensive knowledge of primitive materials

Understanding primitive materials: an international objective

- MarcoPolo-R: selected for the assessment study phase of M3-class missions of the Programme Cosmic Vision 2015-2025 of ESA in Feb. 2011

Supported by
> 575 European scientists

- On-going selected projects:

Hayabusa 2: phase D at JAXA, launch in 2014/15

OSIRIS-Rex: selected in NASA New Frontiers, launch in 2016

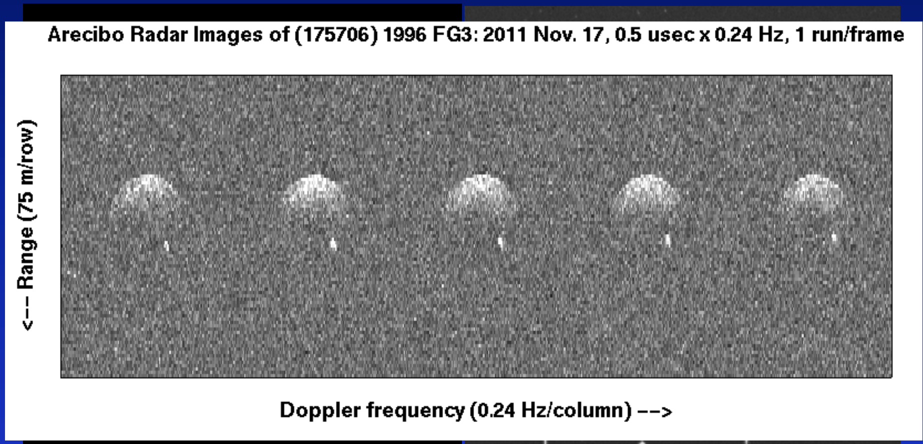
Common objectives:

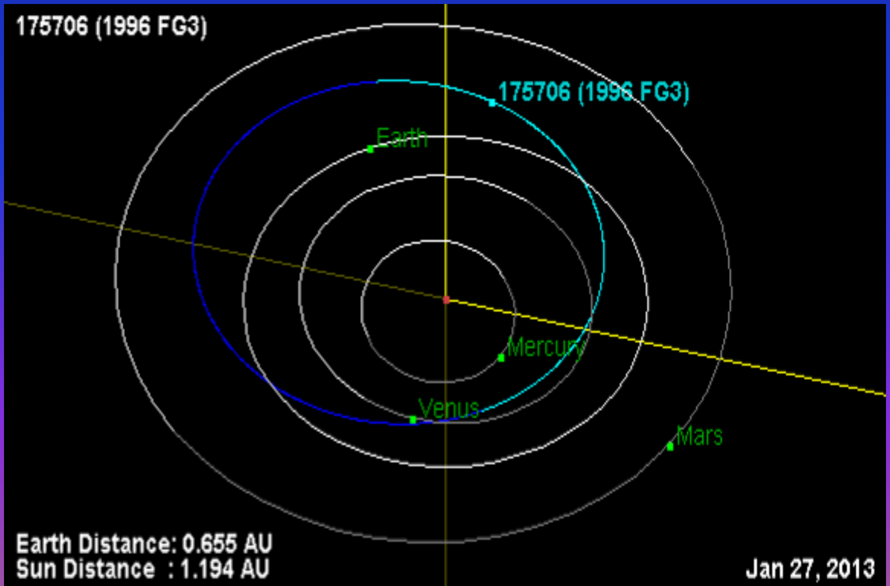
Origin and evolution of the Solar System, origin of life, Hazard

Require several missions to understand the diversity and to have a comprehensive knowledge primitive materials

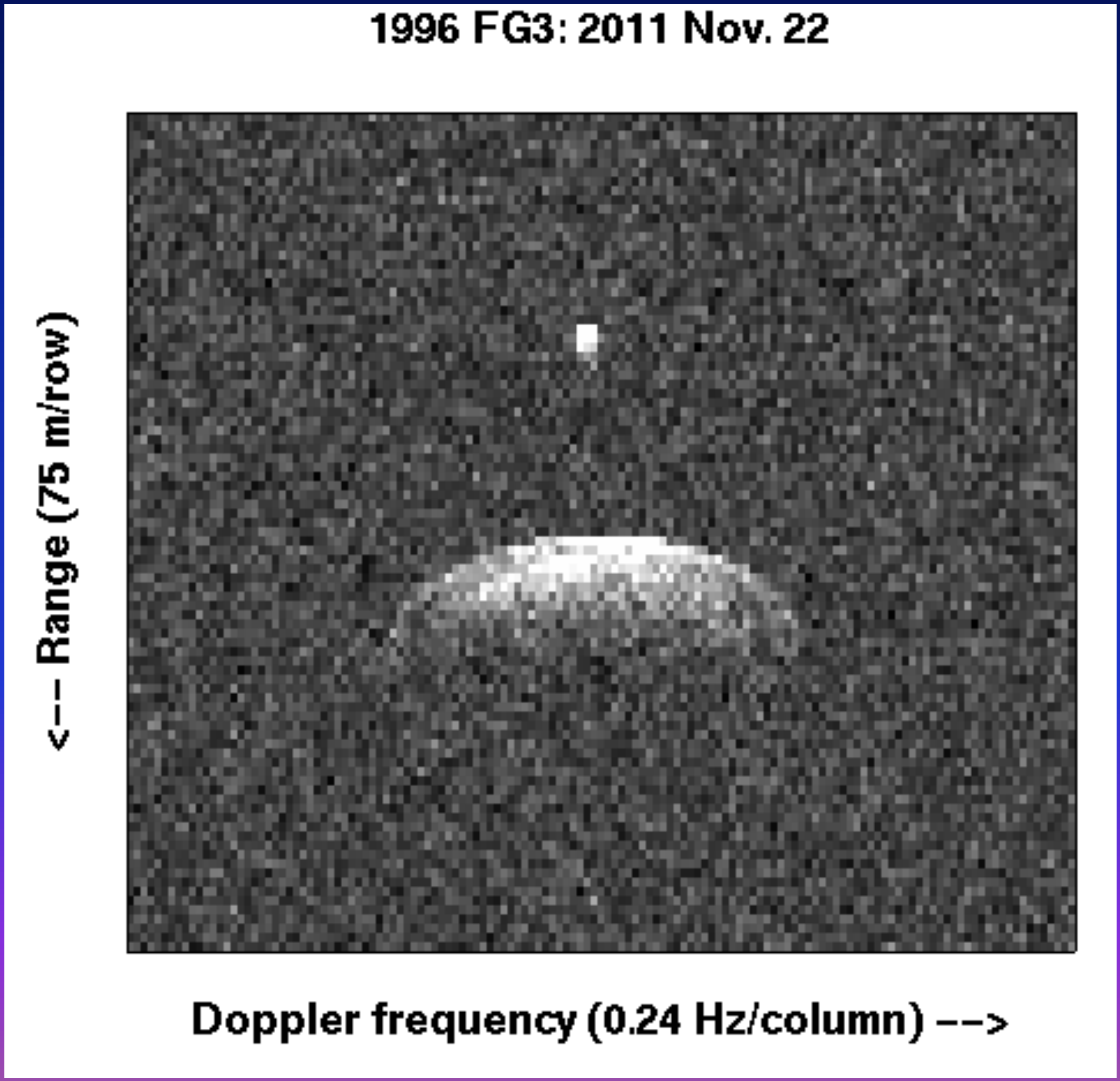
Baseline MP-R Target: (175706) 1996FG3
Dynamical properties

- **Class: C-type binary**
- **Orbit: 0.69 to 1.42 AU from Sun**
- **Inclination: 1.99 deg**
- **Eccentricity: 0.3498**
- **Orbital period: 1.08 years**



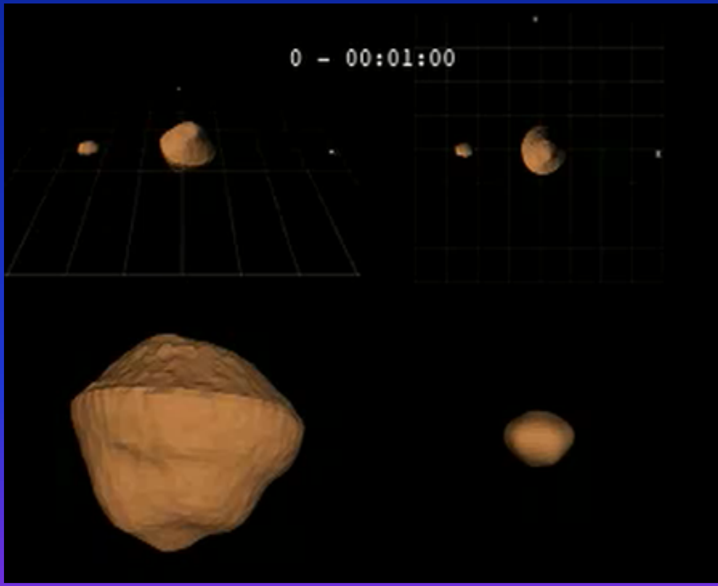


Baseline MP-R Target: (175706) 1996FG3
Evidence for an equatorial ridge



1999 KW4

Ostro et al. (2005)



L. Benner Courtesy

Selected Physical Properties

Absolute mag.	H = 18.005	JPL/Horizons
	H = 17.76+-0.03	Pravec et al. 2006
Spectral class:C		Bus and Binzel 2002
Albedo	p_v = 0.029+0.026-0.012	Mueller et al. 2011
Diameter	1.9 +0.55-0.42 km	Mueller et al. 2011
Secondary Diameter	~ 0.5 km (radar)	

Binary system: (Pravec et al. 2006)

Primary	P = 3.5942 +-0.0001 h
Secondary	P = 16.14 h

Pole direction l = 242 +-96, b = -84 +14 -5 deg

Mass and Density: ***Preliminary*** Results

L. Benner Courtesy

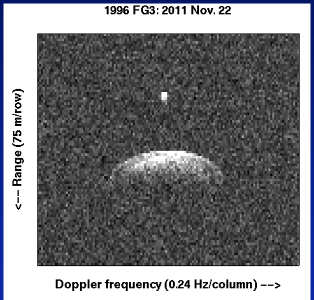
Maximum separation	= 2.55 km (2011 Nov. 22)
Subradar latitude	= 16 deg
-> Mass	= 3.3×10^{12} kg
-> Density	= 0.9 g/cm^3
	(previous estimate: 1.4 g/cm^3)

PLEASE NOTE:

1. Ignores mass of secondary
2. Assumes primary is a sphere with D = 1.9 km
3. Assumes orbit is circular
4. Uncertainties could easily be >30%

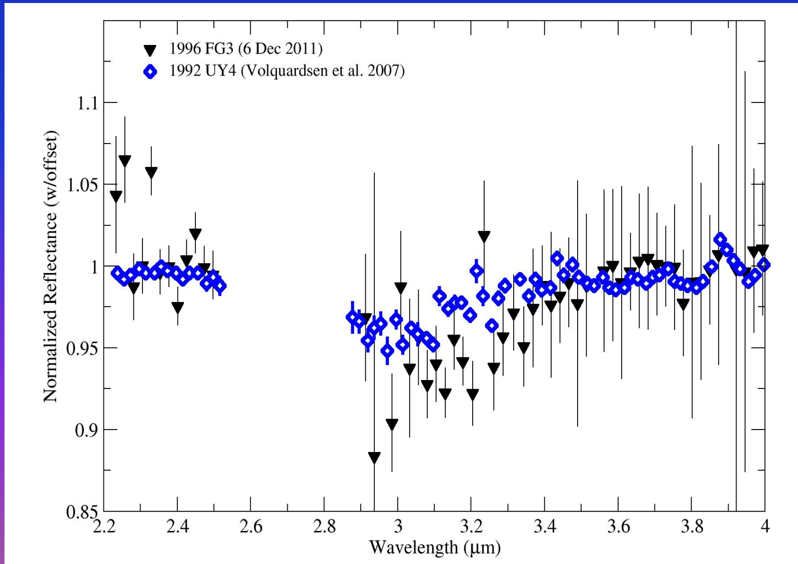
1996FG3 in the 3-μm region

- **Only second NEO found with a 3-μm band**
- 6 Dec data best
  - 20 Nov data too high phase for this thermal model
  - 24 Dec data consistent but rattier



- **Band of ~5-10%, Pallas-types**
  - **Band depth dependent upon exact thermal correction**
- **Interpreted as hydrated/hydroxylated**

From A. Rivkin et al.



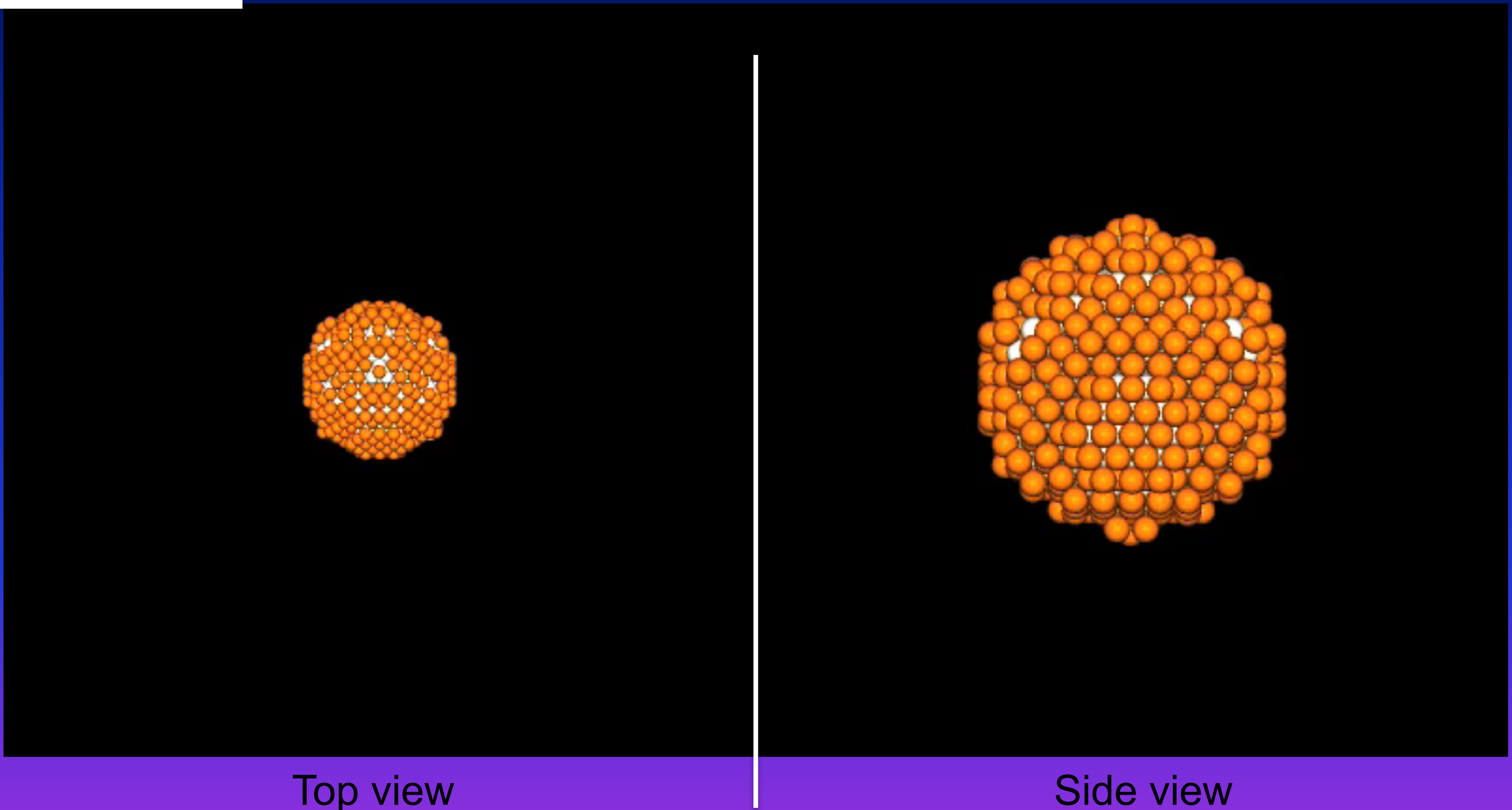
Added science value of a binary target

- Binary asteroids represent 16% of the NEO population
- Several formation mechanisms have been proposed, each starting from a single body which separates into two components
- Determining the physical properties of a binary would help discriminating between the different formation scenarii
- According to some scenario, some portions of the surface were originally within the progenitor, thus we may be able to probe a recent asteroid interior without having to drill into it

Rotational breakup as the origin of small binary asteroids

Kevin J. Walsh[1,2], Derek C. Richardson[2] & Patrick Michel[1]

nature International weekly journal of science
LETTERS
Vol 454 | 10 July 2008



Top view

Side view

Note: original surface (orange) particle go from the pole to the equator; the pole is eventually left with fresh (white) particles (ideal for sampling fresh material).

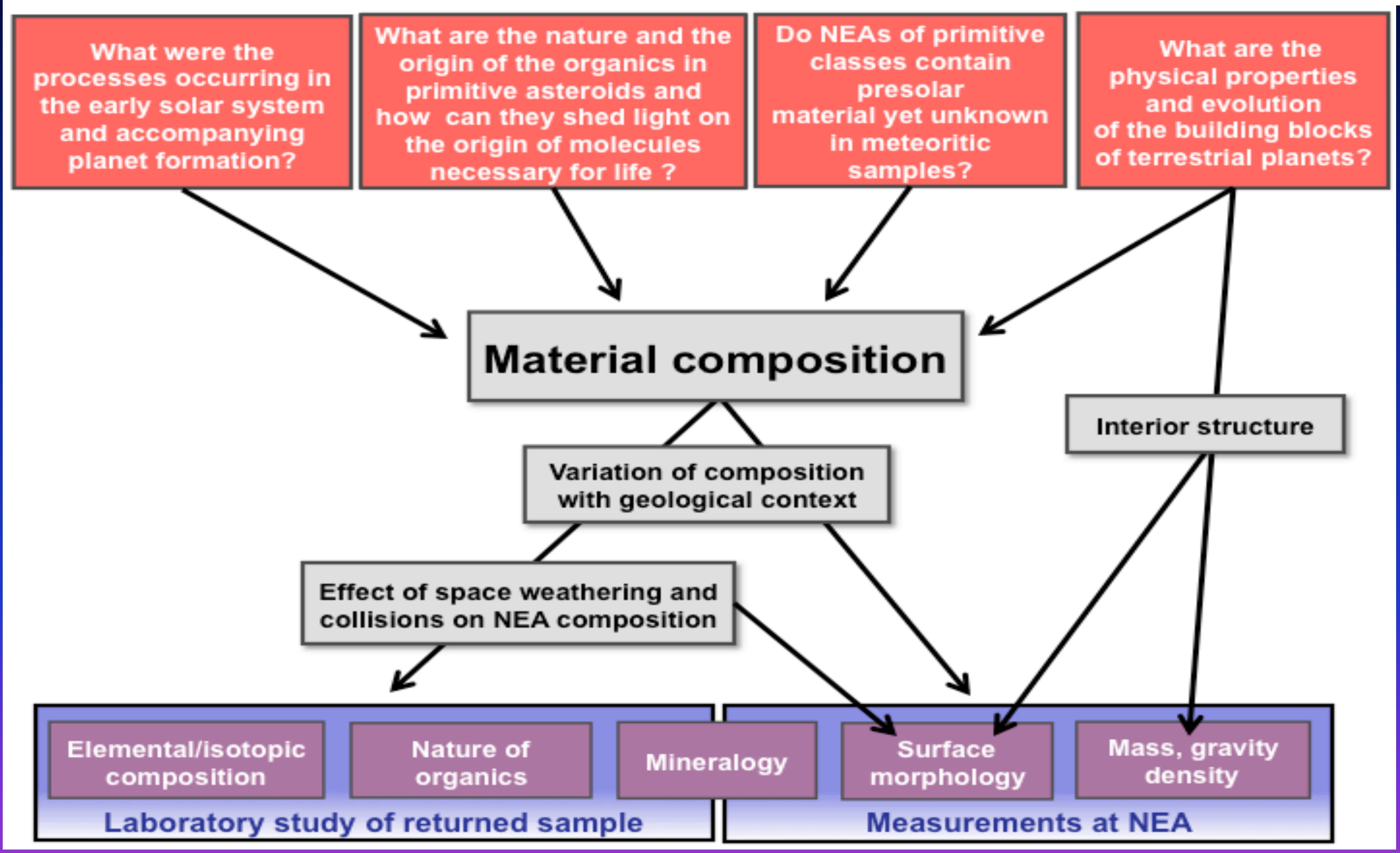
Advantages of the binary target for A sample return mission

- maximize the scientific return of the mission,
- offer advantages for orbiter dynamics

- The presence of a satellite of the target asteroid will allow us to know the mass of the primary
- Precise measurements of the mutual orbit and rotation state of both components can be used to probe higher-level harmonics of the gravitational potential, and therefore internal structure.
- A unique opportunity is offered to study the dynamical evolution driven by the YORP/Yarkovsky thermal effects.
- Possible migration of regolith on the primary from poles to equator revealing fresh (previously subsurface) material on the pole (good candidate site for unaltered sample collection)

1999 KW4
(image Radar)

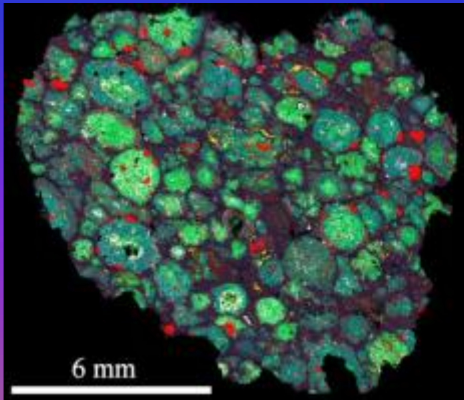
MarcoPolo-R will provide insights…



Laboratory investigation of returned samples

High spatial resolution and analytical precision are needed:

- **High precision analyses - including trace element abundances to ppb levels and isotopic ratios approaching ppm levels of precision**
- **High spatial resolution - a few microns or less**
- **Requires large, complex instruments – e.g. high mass resolution instruments (large magnets, high voltage), bright sources (e.g. Synchrotron) and usually requires multi-approach studies**



MarcoPolo-R

Baseline Payload

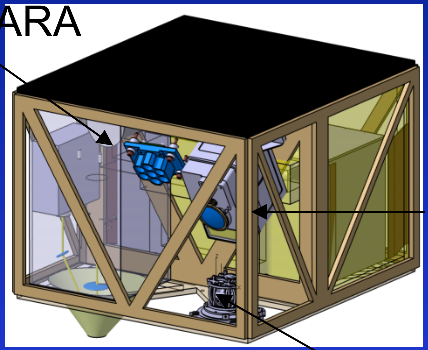
	Spatial resolution		
	VIS imaging	VIS/IR spectrometer	Mid-IR instrument
Global characterisation	Order of dm	Order of m	Order of 10 m
Local characterisation	Order of mm	Order of dm	Order of dm
Context measurements	Hundred µm	-	-

	Wide Angle Camera (WAC)	**Narrow Angle Camera (NAC)**	**Close-Up Camera (CUC)**	**Visible Near Infrared spectro. (VisNIR)**	**Mid-Infrared spectro. (MidIR)**	**Radio Science Experiment (RSE)**	**Neutral Particle Analyser (NPA)**
Mass [kg]	2.0	8.92	0.82	3.6	3.0	Contained in the resources of the radio subsystem	2.2
Volume [mm]	237x172x115	520x380x197 250x170x120	364x78x68	270x110x90 150x180x82	160x220x370	Contained in the resources of the radio subsystem	200x200x100
Power [W] average	11.5	13.5	12.5	18	2		11
Data volume single measur.	67 Mbit	67 Mbit	67 Mbit	0.45 Mbit	360 Mbit	Data recorded in the ground station in real time	0.72 kbit
Heritage	Rosetta, ExoMars, ISS, Bepi Colombo	Rosetta, ExoMars, ISS, Bepi Colombo	Rosetta, ExoMars, ISS, Micro-rover (ESA)	Mars/Venus Express, Rosetta	SMT, TechDemSat		Bepi Colombo

Optional payloads: lander with payloads, laser altimeter, seismic experiment

MarcoPolo-R Proposed Lander Packages

On the basis of MASCOT (a ~10kg lander for the Hayabusa 2 mission), landers with various instrument complements are studied as optional payload for MP-R

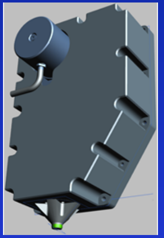


MASCOT

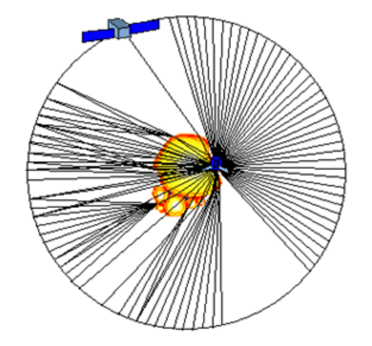
MAPOSSI
- LIBS
- APX
-Thermal Mapper
- Mößbauer Spectrometer,
- IR-spectrometer (MicrOmega)
- Camera
- optional elements

FANTINA
- Radar Tomographer
- Camera
- optional elements

LIBS for ExoMars
© DLR



MicrOmega
for MASCOT
© IAS



Concept of
Radar Tomogapher
Image: IPAG

Schedule

Advisory structure

- **Class M3 Mission: up to ca. 470 MEuros**

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~~

End phase A Dec. 2013 - **TBC-SPC**

Phase B1 kick-off Jan 2014 for the selected mission

Launch 2024

Advanced Study Technology
Preparation Division

CDF Study

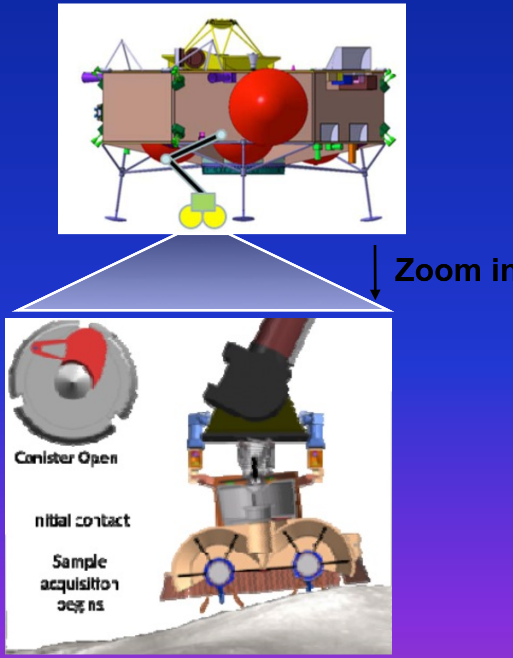
(Concurrent Design Facility)

Main science objective:

- Earth-based analysis of samples (~ 30-100 grams) returned from a primitive asteroid (1996 FG 3, binary)

Mission features:

- Launch with Soyuz-Fregat. Both chemical and electric propulsion investigated (7-9 year mission). Chemical looks challenging
- Main spacecraft + re-entry capsule
- Touch and go sampling (various concepts investigated, see example on the right-hand side)



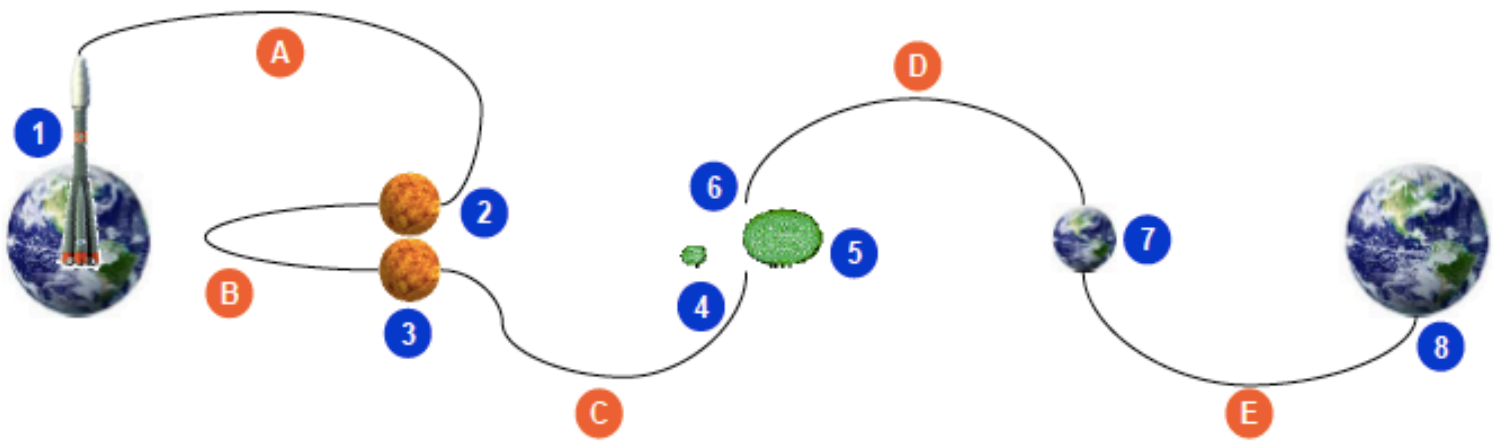
Key technologies: GNC for asteroid landing/sampling; sampling, transfer and containment system; heat shield for high Earth re-entry speeds

Payload: set of wide, narrow and close-up cameras, visible/ near-IR & mid-IR spectrometer, radio science, total mass: ~ 20 kg

Ongoing assessment study focuses on ESA-only mission

Overall Mission Architecture

1. Baseline Architecture (Option 1b)



1 Soyuz ST launch from Kourou (FR)
2 First Venus Swing-by
3 Second Venus Swing-by
4 Arrival to 1996 FG3
5 Observation & sample collection
6 S/C Departure (Return to Earth)
7 Earth Swing-by
8 ERC return to Earth

EP thrust and coast arcs

Technology activities

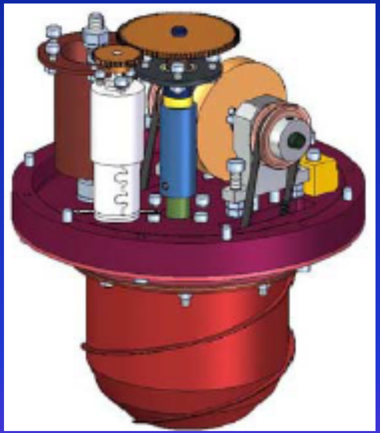
1. Coming from various sources
   a. Mandatory generic programme → Technology Research Programme (TRP)
   b. Mandatory Science programme → Core Technology Programme (CTP)
   c. Optional Mars Robotic Exploration Propagation (MREP) Programme
   d. Optional generic General Support Technology Programme (GSTP)
2. **MP-R is not a critical mission in terms of TRL level.** High-precision Guidance, Navigation & Control (GNC) was found to need more attention in the previous Marco Polo study. Since then:

   A technology activity showed meanwhile that we were on the right track and confirmed that high-precision landing on a small body works

GNC (Guide, Navigation & Control) for NEO missions – Phase 2, 500 k€ (completed – successful)

Sampling - technology

1. SENER company + Comet Nucleus Sample Return (CNSR) activities in the 90's → corer works!!
   a. Systematically collected over 50 grams
   b. Forces and torques within the specifications
   c. Very simple system
2. Other activity by Astrium internal R&D: looked at a different concept



3. For touch and go:

   a. " Sampling tool mechanism for low-gravity bodies", activity funded by MREP, 700k€, split into two phases. Phase 2 will test sampling tool in microgravity, i.e. parabolic flight
   b. Same environment requirements as for MP-R → will be updated after the Science Study Team feedback on soil properties
   c. The activity is very open right now
   d. **Study Kick-Off in July 2012**

Earth re-entry - technology

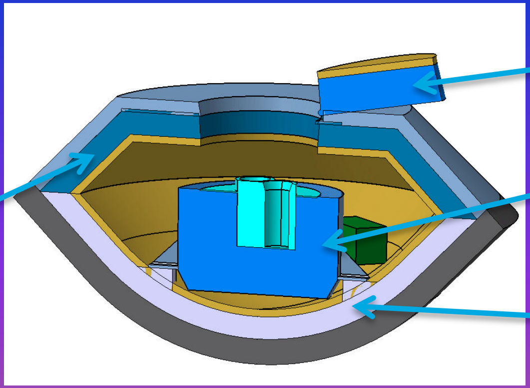
A few main areas:

   a. Heat shield, most critical one
   b. Crushable material, if no parachute
   c. Parachute otherwise (only subsonic looked at)
   d. Capsule stability
   e. Radiation environment

2. All these areas are addressed in various technology activities
3. Given the current status of all, very high chance of success

Diam=0.92 m
Mass=54 kg
FPA =-9 deg!
75 mm crushable material

Capsule (example)

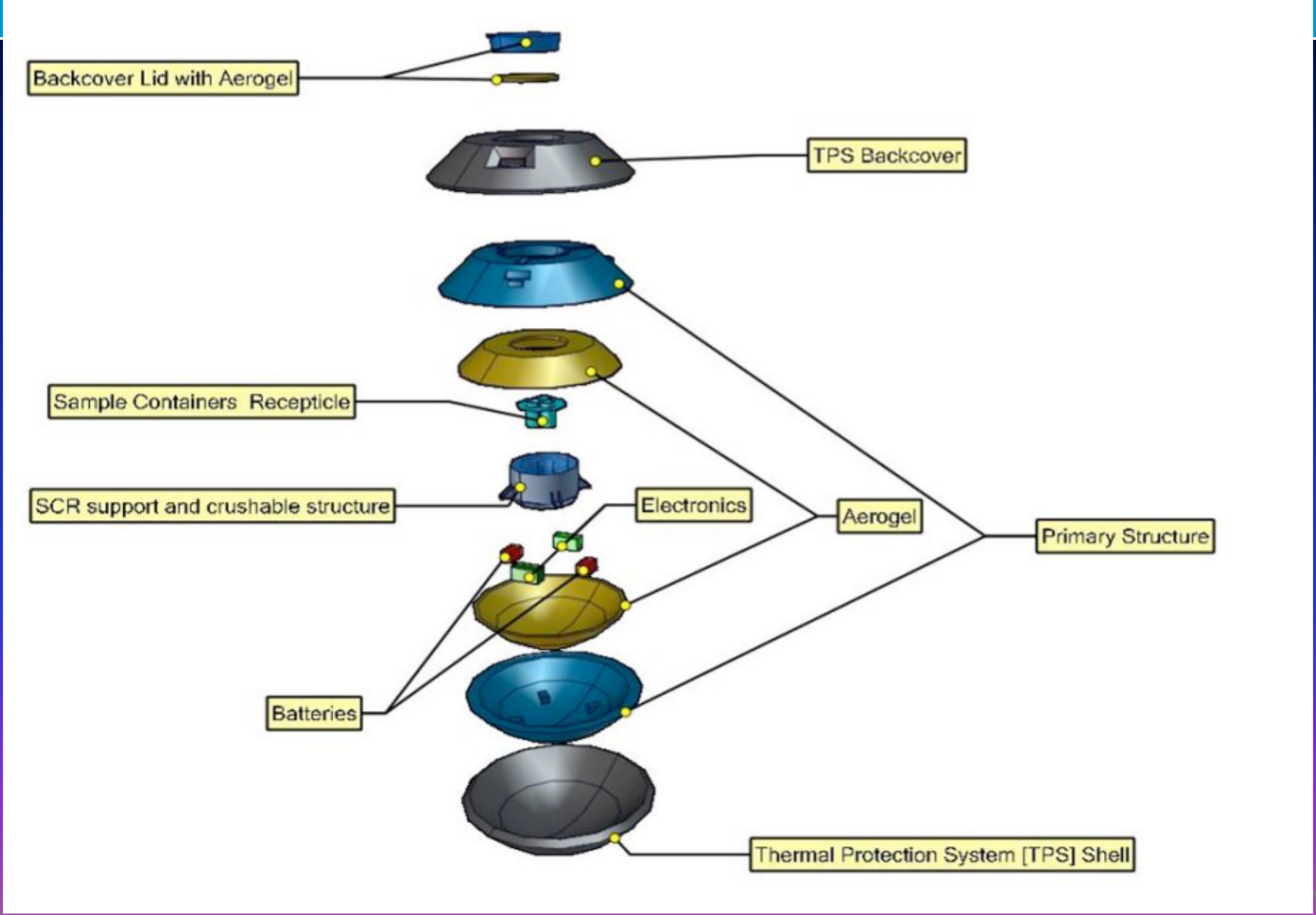


LID

Crushable material
AL honeycomb 1/8 – 5052 – .001: Crush strenght 1.8MPa. Denisty = 72 kg/m3

BC-cold structure
1mm CFRP skin; 38 mm AL honeycomb core

FS – cold structure
1mm CFRP skin; 38 mm AL honeycomb core


Backcover Lid with Aerogel
TPS Backcover
Sample Containers Recepticle
SCR support and crushable structure
Electronics
Aerogel
Primary Structure
Batteries
Thermal Protection System [TPS] Shell

ESA - Technology

In total, **ESA is investing close to 4.5M€**

in activities directly relating to MP-R and other technologies are being developed in other programmes which are indirectly related to MP-R

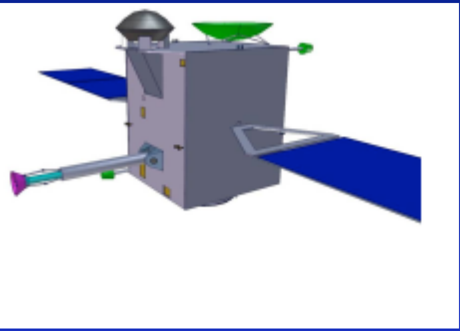
in addition to all national activities such as the “instrument” studies initiated in the frame of the Declaration of Interest (~ 20 nationally-funded studies are ongoing).

Baseline mission

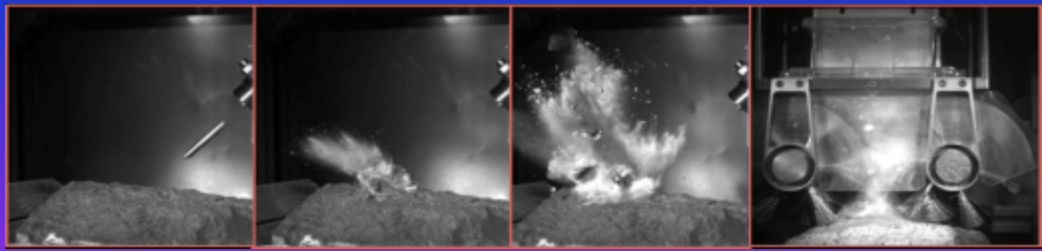
Under industrial study (Feb. 2012- end 2013):

Target: 1996 FG3, 3-6 months stay time
Launch window: 2021/2024 and sample return in 2029/Soyuz

Single primary spacecraft, carrying:
- **Earth Re-rentry Capsule (ERC)**
- **Sample acquisition and transfer system (SAS)**

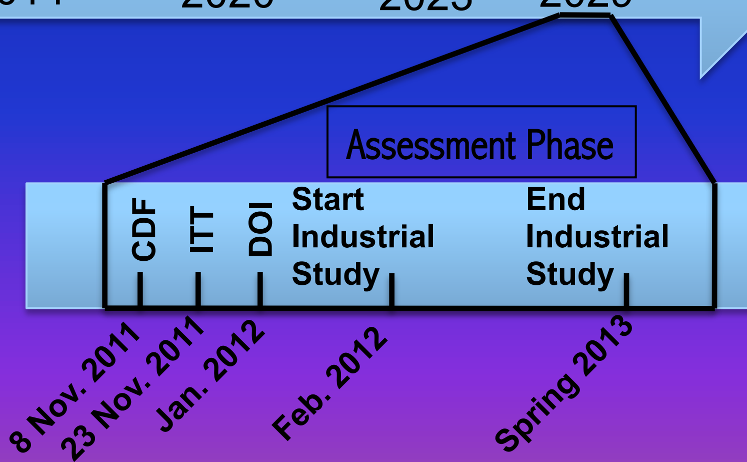


Touch and go sampling mechanisms (non-exhaustive list):
- **Brush or cutting wheels**
- **Corers**
- **Gaseous transport devices**



Sample device should collect a minimum of 100 g sample
(dedicated study starting in July 2012)

Programmatic International Framework



MarcoPolo-R (ESA)

- **binary, peculiar C-type (3 micron band)**
- **different technology for sampling**

MarcoPolo-R will use a combination of in situ and laboratory measurements to:

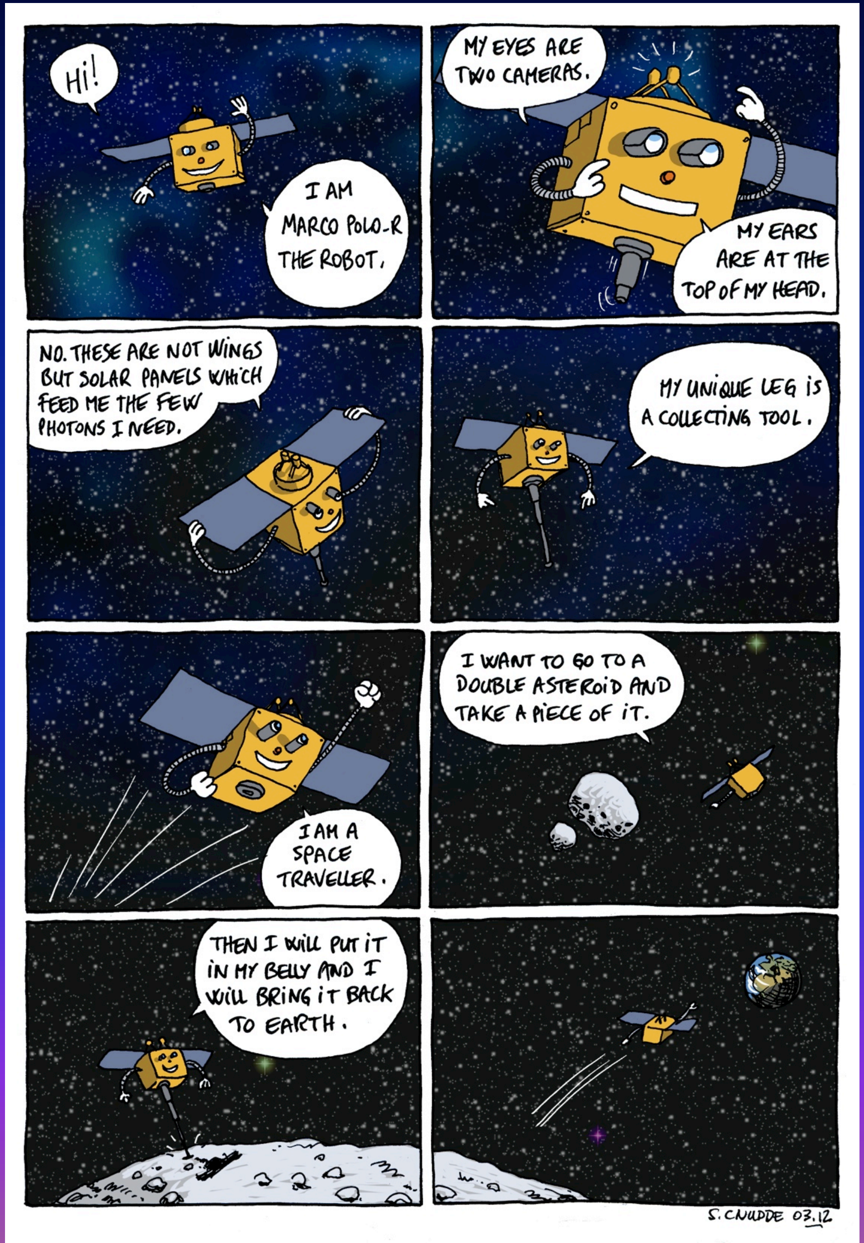
- ✓ provide a unique window into the distant past
- ✓ allow scientists to unravel mysteries surrounding the birth and evolution of the solar system
- ✓ involve a large community, in a wide range of disciplines

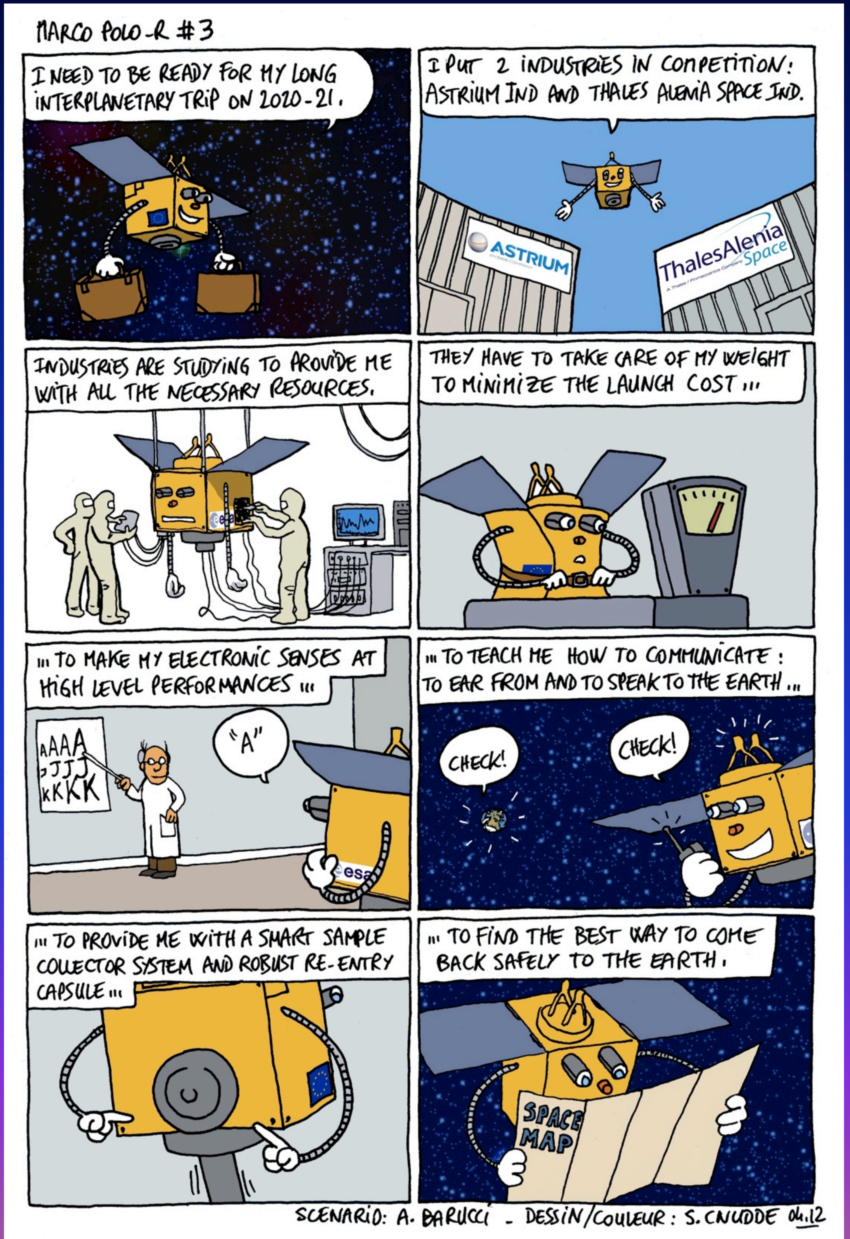
Planetology — **Astrobiology**
Nucleosynthesis — **Cosmochemistry**

- ✓ retain samples for future advances through a Curation and Distribution Facility
- ✓ demonstrate key capabilities for any sample return mission
- ✓ generate tremendous public interest

David Hardy

An easy case for outreach





MarcoPolo-R Mission

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

European Community Supporters:

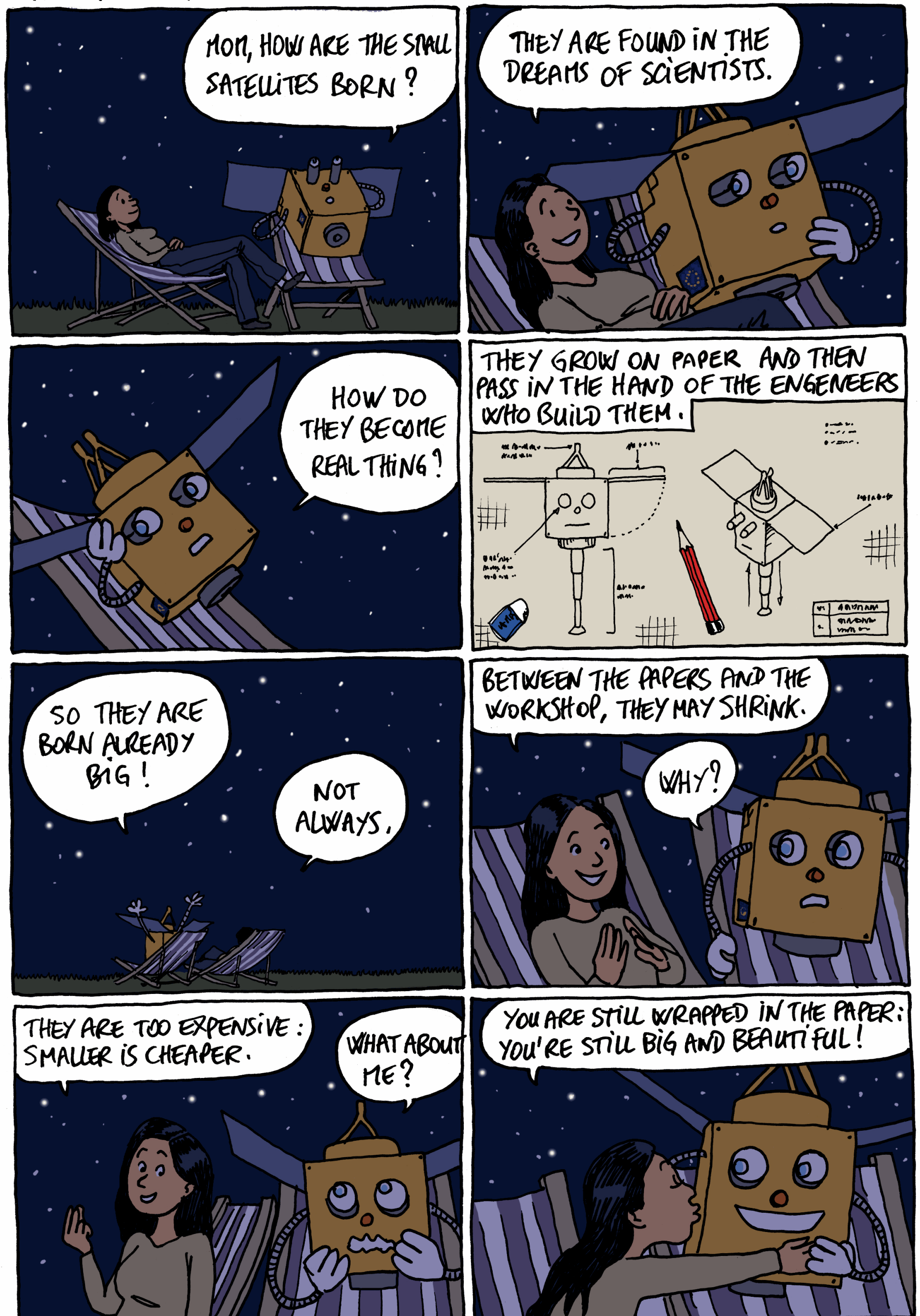
577 scientists (May 12, 2012), 25 countries

International collaboration is open

MarcoPolo-R is on Faceboook:

http://www.facebook.com/pages/MarcoPolo-R-Space-Mission/40232049502

MARCO POLO-R #5



MARCELLO FULCHIGNONI & SYLVAIN CNUDDE 05.12