FORMATION SCENARII OF ASTEROID BINARIES AND IMPLICATIONS FOR THE SCIENCE RETURN OF THE MARCOPOLO-R MISSION

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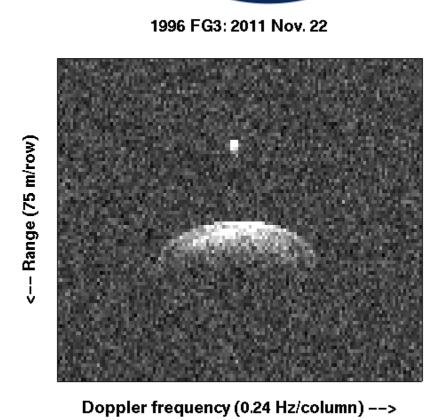
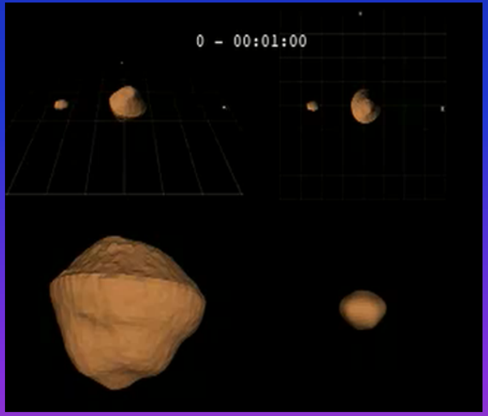


What do observations tell us about small binaries

- They represent 15% of the Near-Earth Object (NEO) population
- Most of them seem to have similar properties:
  - Rapidly rotating primaries
  - Spherical/oblate primaries
  - Close secondaries
  - Low eccentricities

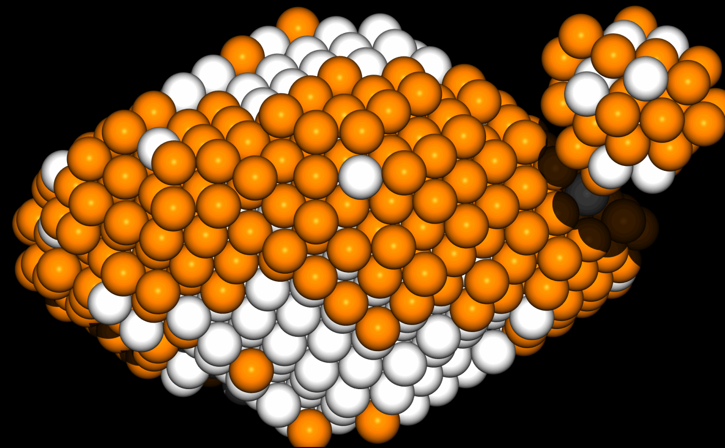


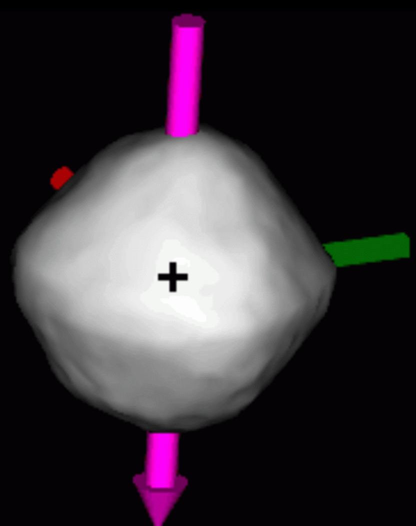
1999KW4, Ostro et al.

Top Shapes and Ridges

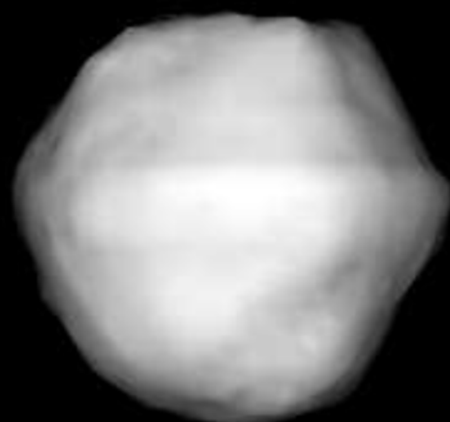
1999 KW_4 radar model, Ostro et al. 2005

Formation model, Walsh et al. 2008





Single asteroid 1999 RQ_{36}
Howell et al. 2008, ACM



Binary 2004 DC
Taylor et al. 2008, ACM

Šteins from Rosetta Images

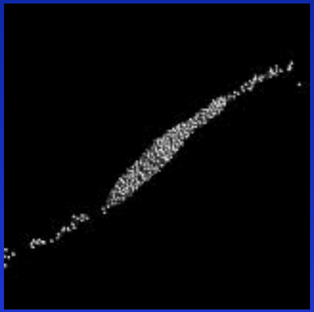
Added science value of a binary target for a sample return space mission

- Binary asteroids represent 15% of the NEO population
- Several formation mechanisms have been proposed, each starting from a single body which separates and forms two components (e.g. Walsh et al. 2008, Jacobson&Scheeres 2011)
- Determining the physical properties of a binary would help discriminating between the different formation scenarii
- According to some scenario, some portions of the surface would be ideal spots for a sample return space mission
- A binary is an ideal target to study the fascinating geology and surface processes in a low g environment

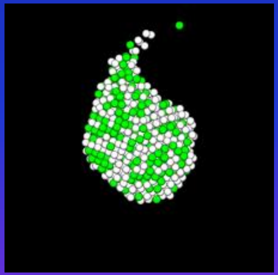
Formation mechanisms of small binaries

- Catastrophic disruption of a large asteroid: formation of aggregates and binaries

- Tidal encounter with a planet fragment a body into a binary system



- YORP spin-up can break a body into a binary system



However, not all 3 mechanisms form binaries with observed properties of NEO binaries, but all imply that these bodies have particular physical properties, which can be checked by a space mission

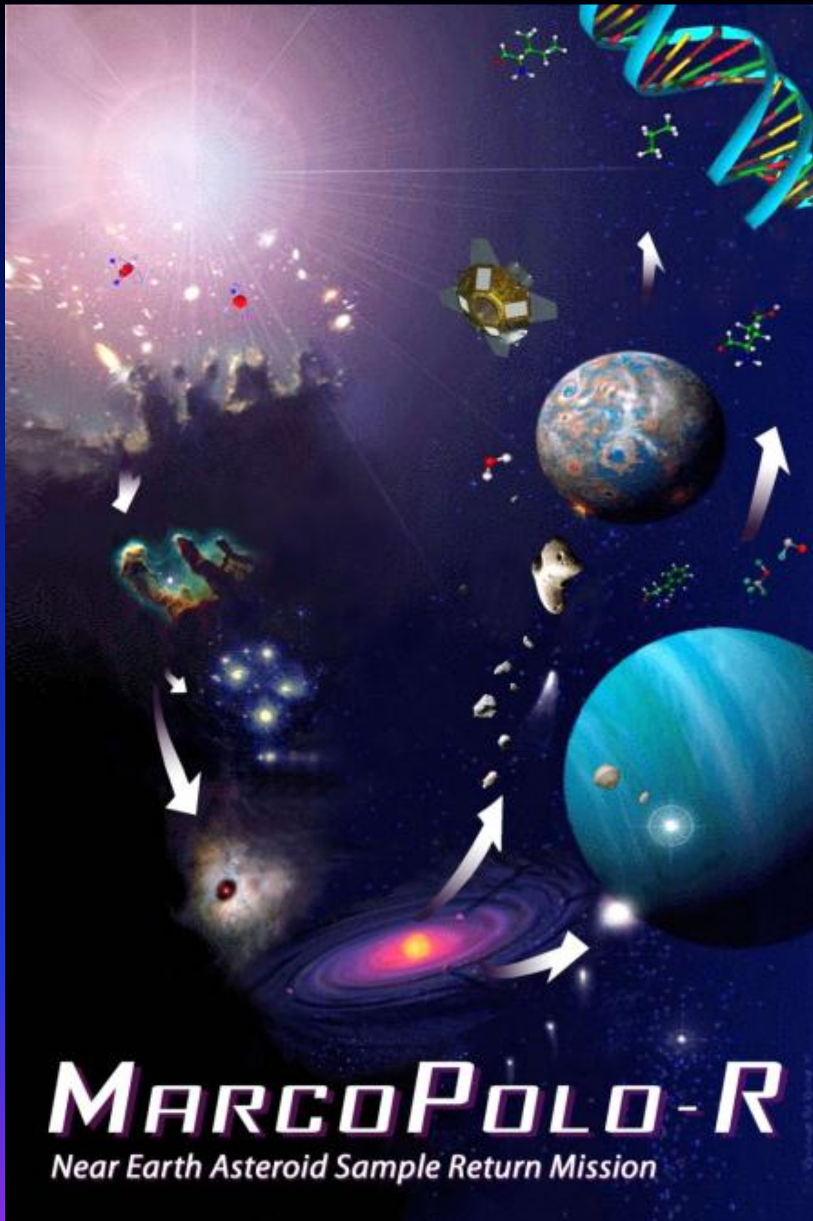
Advantages of the binary target for A sample return mission

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

- ➢ The presence of a satellite of the target asteroid allows having a mass determination in advance of the mission
- ➢ 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 and the associated fascinating geology and surface processes in a low-g environment
- ➢ Possible migration of regolith on the primary from poles to equator reveals fresh (previously subsurface) material on the pole (good candidate site for "fresh" sample collection)

1999 KW4
(image Radar)

Cosmic Vision ESA – M3



Selected in Feb. 2011 for assessment study phase
Next selection step: December 2013

Science Study Team (SST):

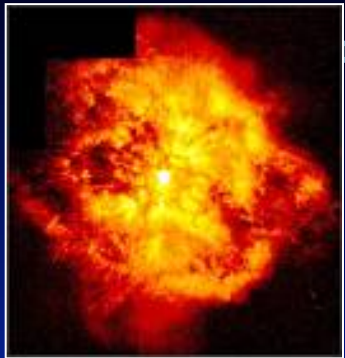
M.A. Barucci (F)	Chair
P. Michel (F)	Co-Chair
J. Brucato (I)	
H. Böhnhardt (D)	
E. Dotto (I)	
P. Ehrenfreund (NL)	
I. Franchi (UK)	
S. Green (UK)	
L. Lara (E)	
B. Marty (F)	

Detlef Koschny
(ESA - Study Scientist)

David Agnolon
(ESA- Study Manager)

Jens Romstedt
(ESA - Study Payload Manager)

MarcoPolo-R addresses a wide range of objectives

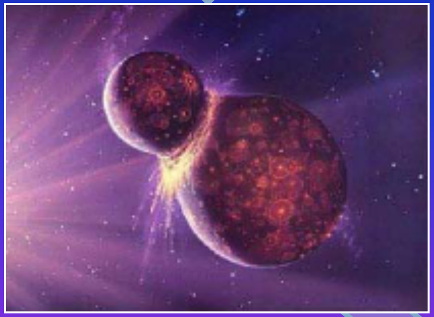


Stars
Stellar nucleosynthesis
Nature of stellar condensate grains

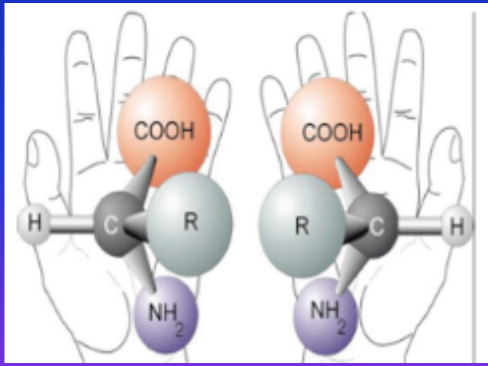
The Interstellar Medium
IS grains, mantles & organics

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

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



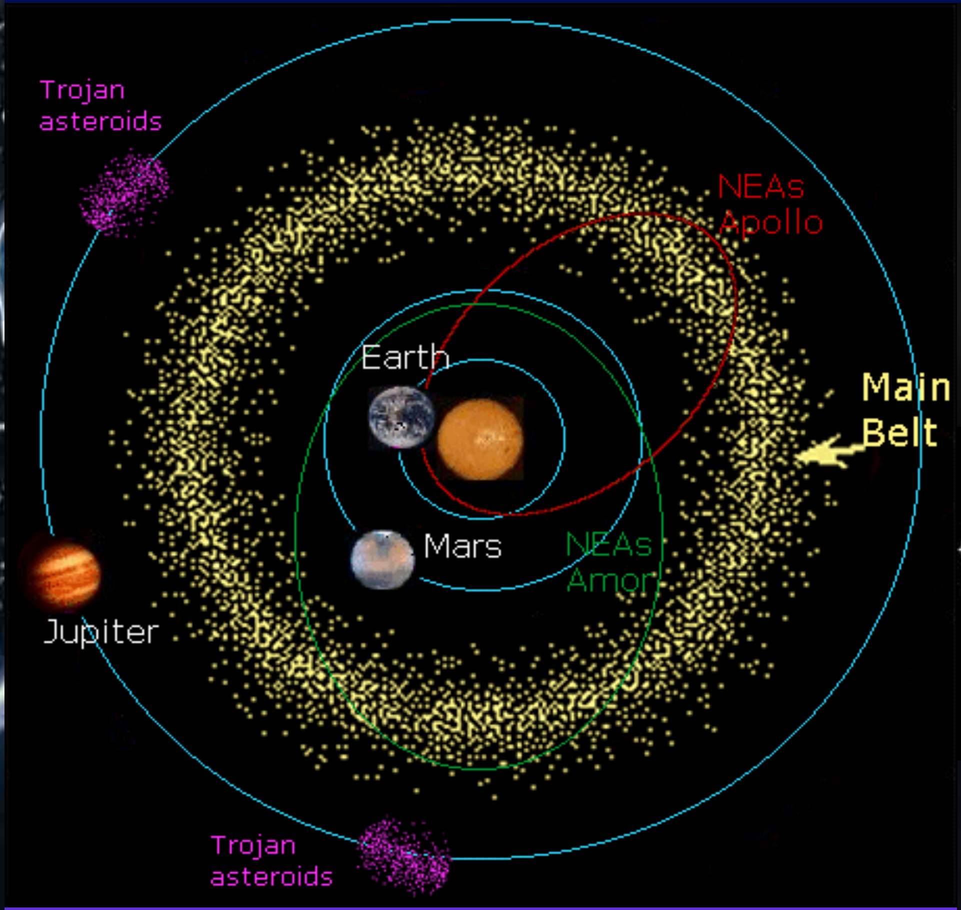
Asteroids
Accretion history,
alteration processes,
impact events,
regolith



Life
Nature of
organics in NEOs

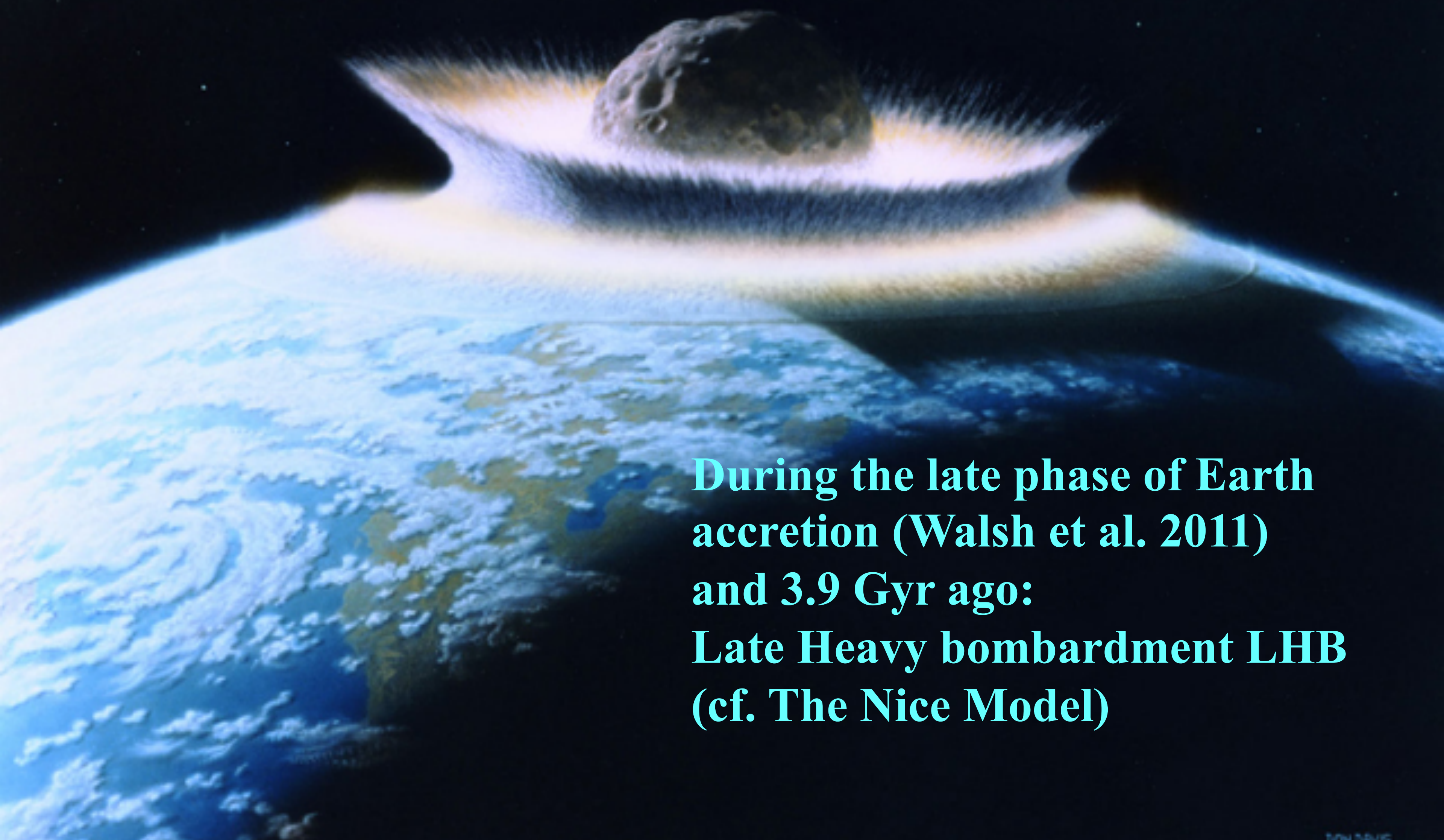
The Earth
Impact hazard
Evolution of life on Earth

Small bodies in our Solar System



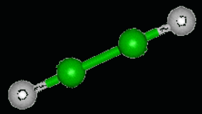
- ➢Several populations: Near-Earth, main belt, Kuiper belt
- ➢ Fate: impact into the Sun, on planets, ejected from the Solar System

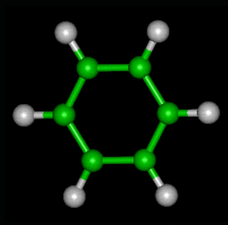
Impacts had both beneficial and destructive effects on the evolution of planetary biospheres

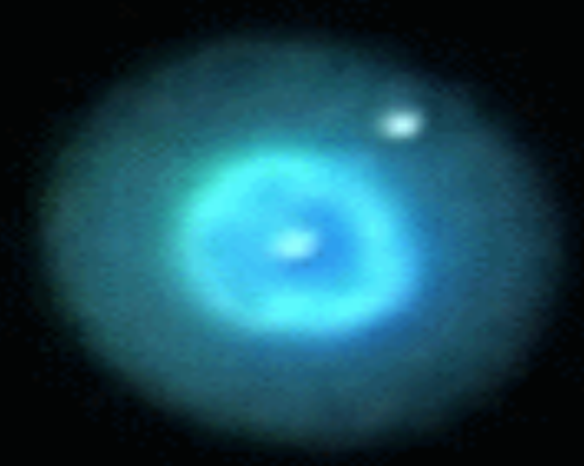


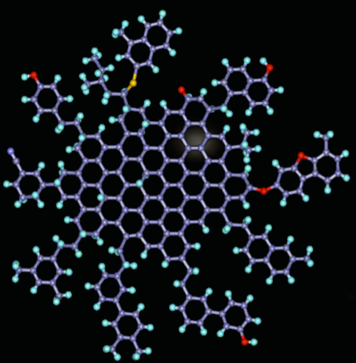
During the late phase of Earth accretion (Walsh et al. 2011) and 3.9 Gyr ago: Late Heavy bombardment LHB (cf. The Nice Model)

Carbon chemistry
From stars to life



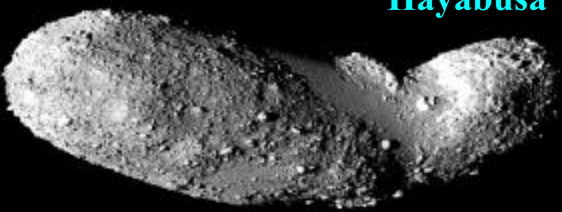




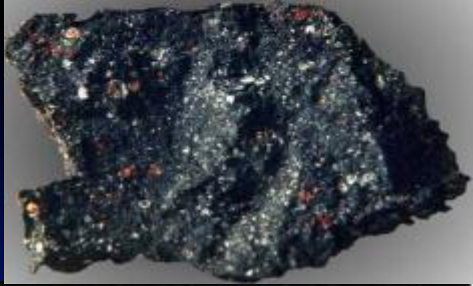


Stardust

Hayabusa

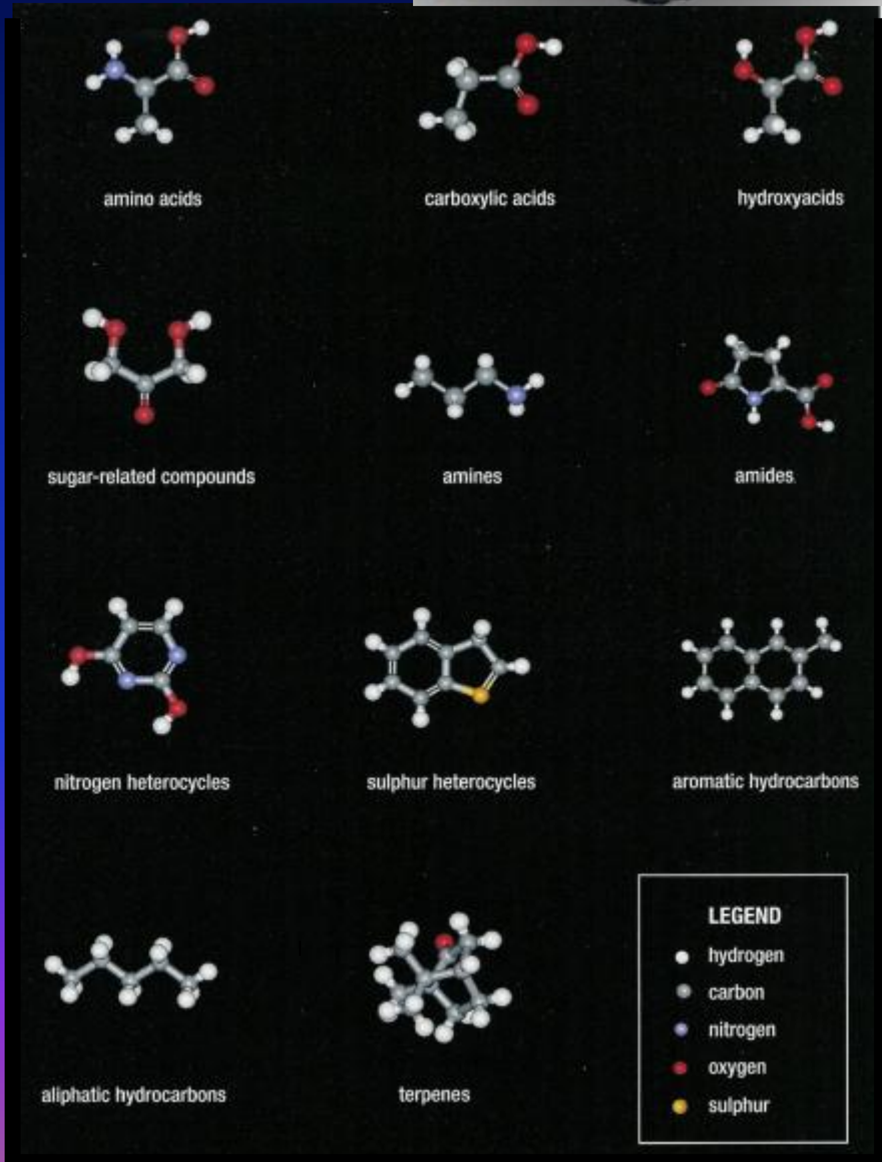


Organic compounds in Murchison

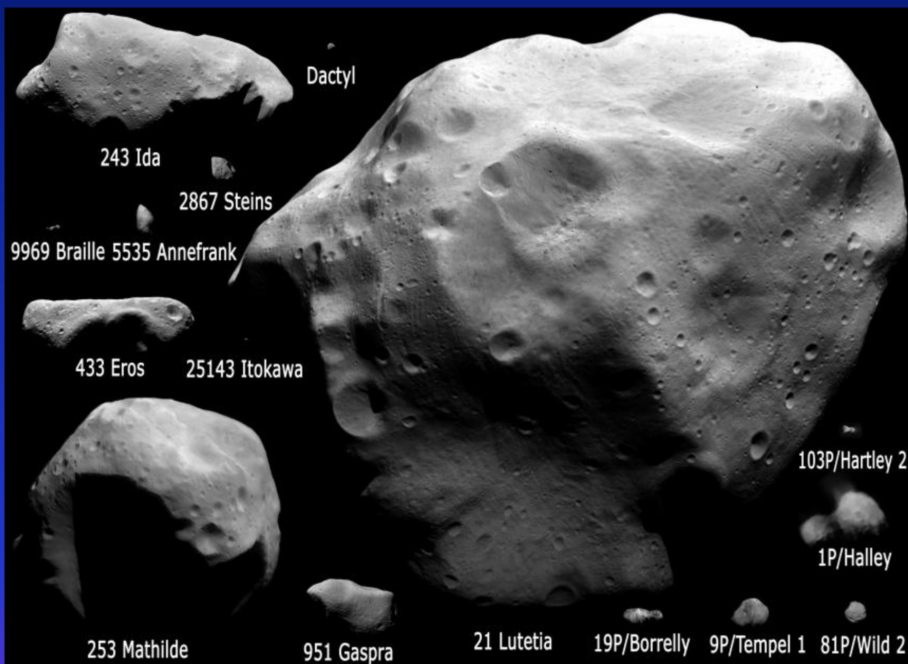


Compound Class	Concentration(ppm)
CO_2	106
CO	0.06
CH_4	0.14
NH_3	19
Aliphatic hydrocarbons	12-35
Aromatic hydrocarbons	15-28
Amino Acids	60
Monocarboxylic acids	332
Dicarboxylic acids	26
α-hydroxycarboxylic acids	14
Polyols (sugar-related)	~24
Basic N-heterocycles	0.05-0.5
Purines	1.2
Pyrimidines	0.06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

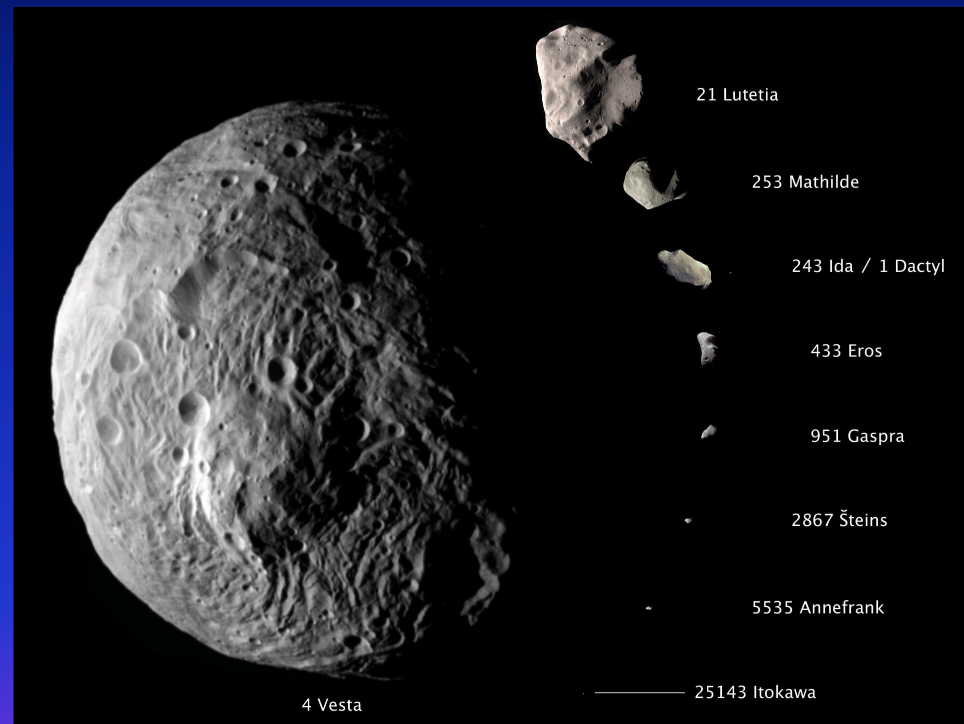
Sephton 2002



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

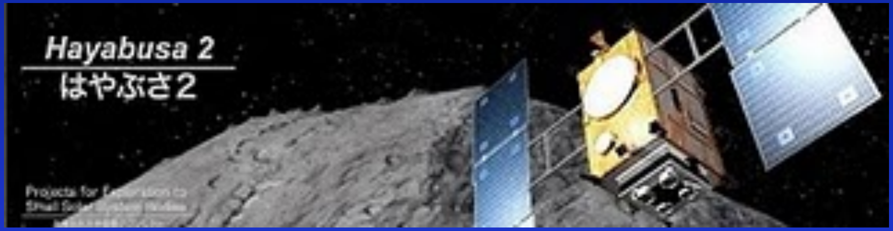
We need several missions to obtain a comprehensive knowledge of primitive materials

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

- On-going selected projects:

Hayabusa 2: phase B at JAXA, launch in 2014



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

Proposed by:
A. Barucci (Obs. Paris, Lead)
P. Michel (OCA, co-Lead),
Supported by > 575 European scientists

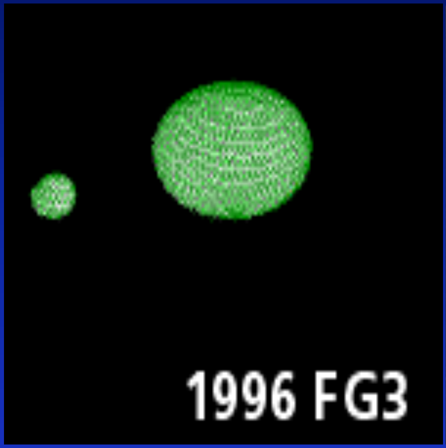
Common objectives:

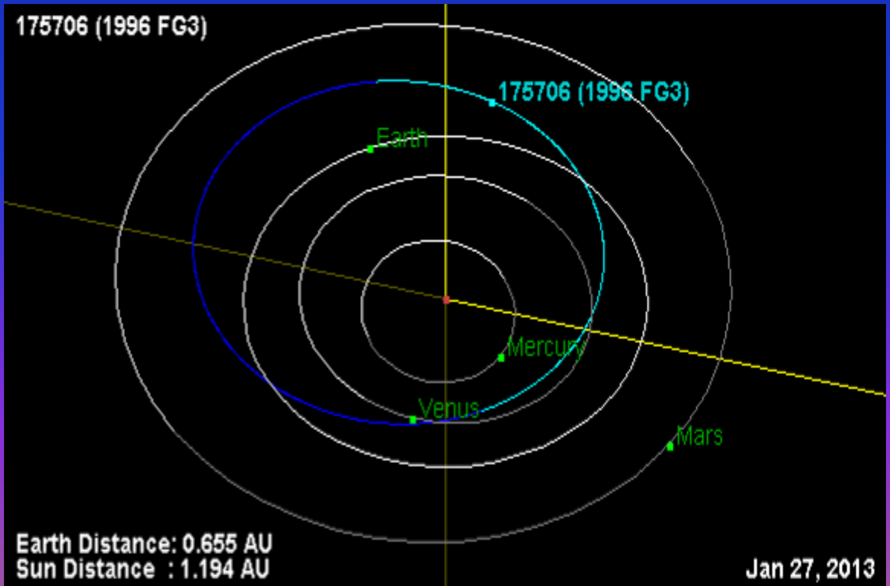
Origin and evolution of the Solar System, origin of life, Hazard

Require several missions to understand the diversity and to have a comprehensive knowledge of 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**





Radar Observations Log

Close Approach Distance = 0.101 AU on 2011 Nov. 23

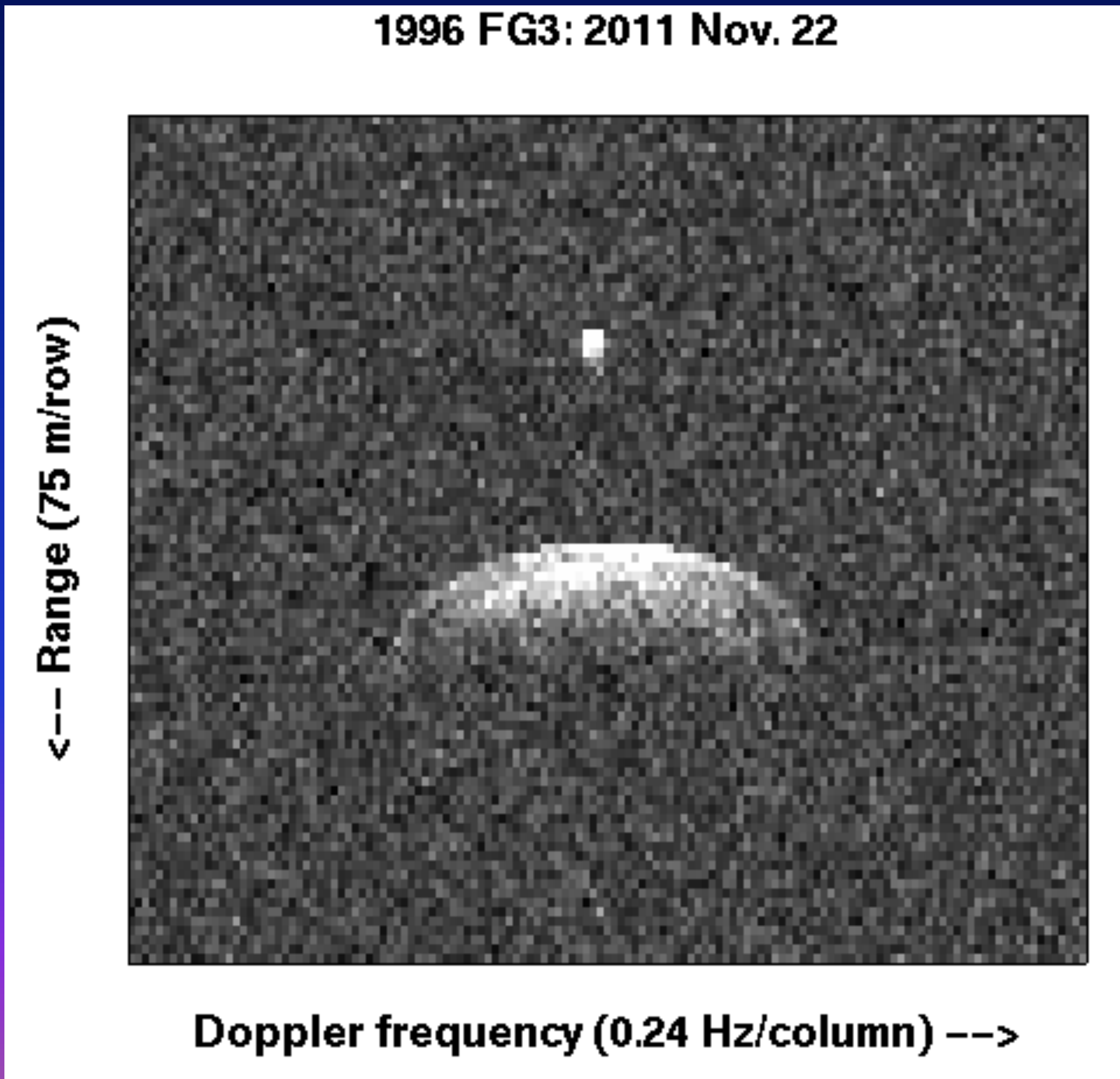
Arecibo

Nov. 6, 17, 18, 20, 21, and 22
Dec. 14 and 17
CW echo power spectra, ranging, & 75 m-resolution images

Goldstone

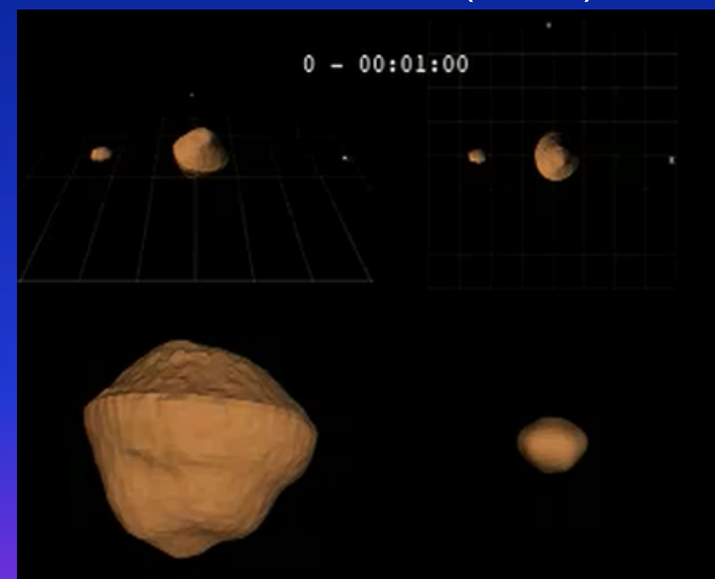
Nov. 20, 21, 22, and 25
CW echo power spectra and 150 m-resolution images

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



1999 KW4

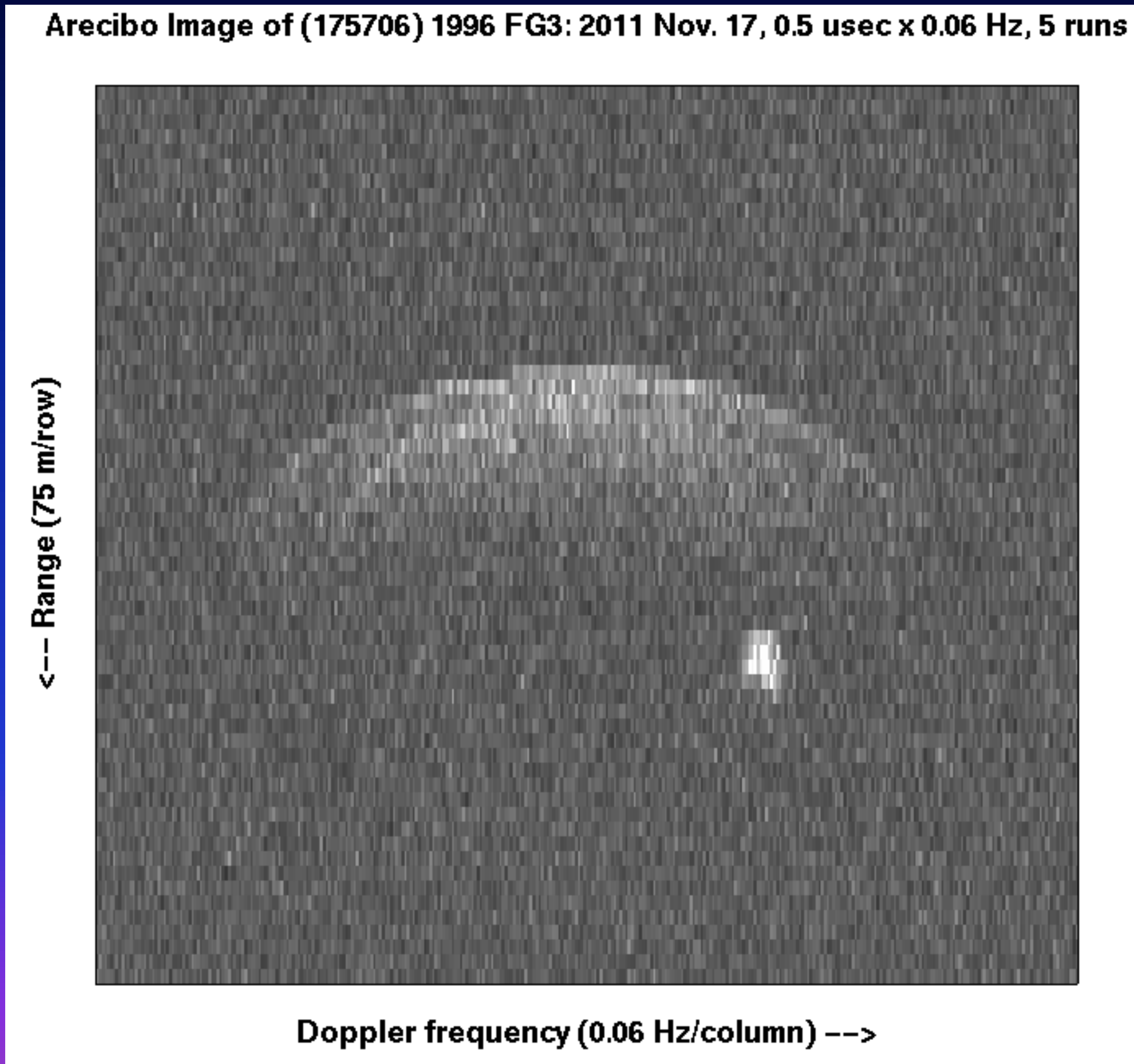
Ostro et al. (2005)



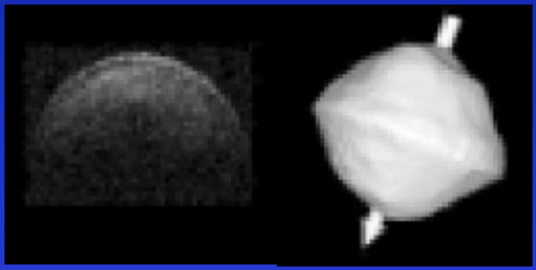
L. Benner Courtesy

1996 FG3: November 17

75 m x 0.06 Hz



1999 KW4



Data Model

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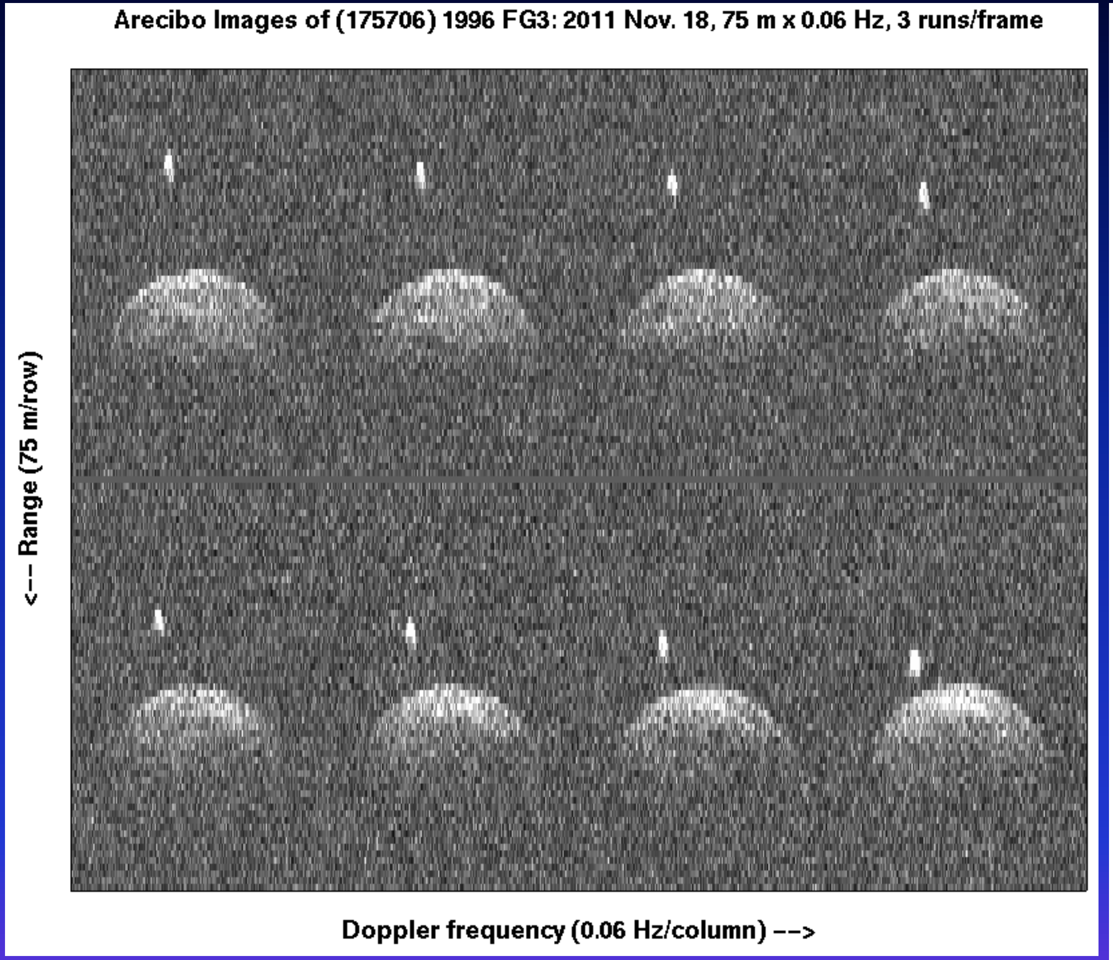
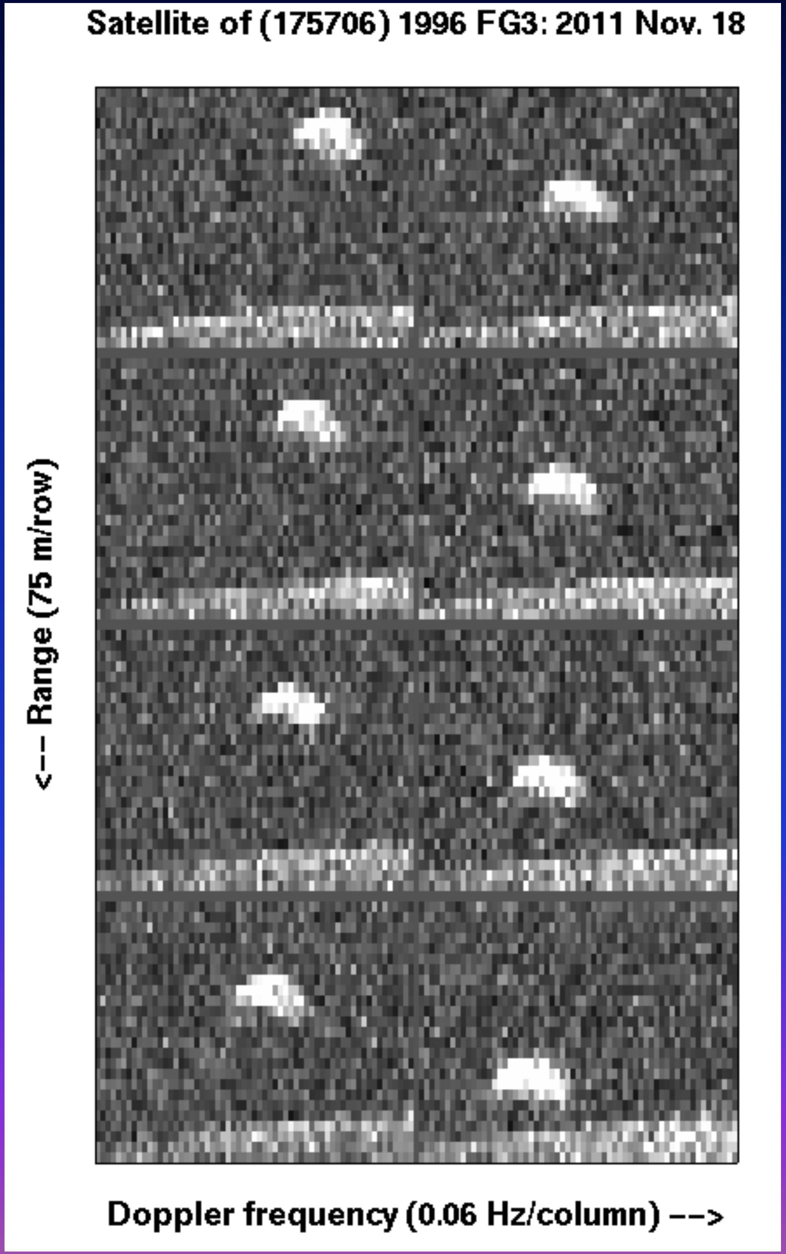
November 18





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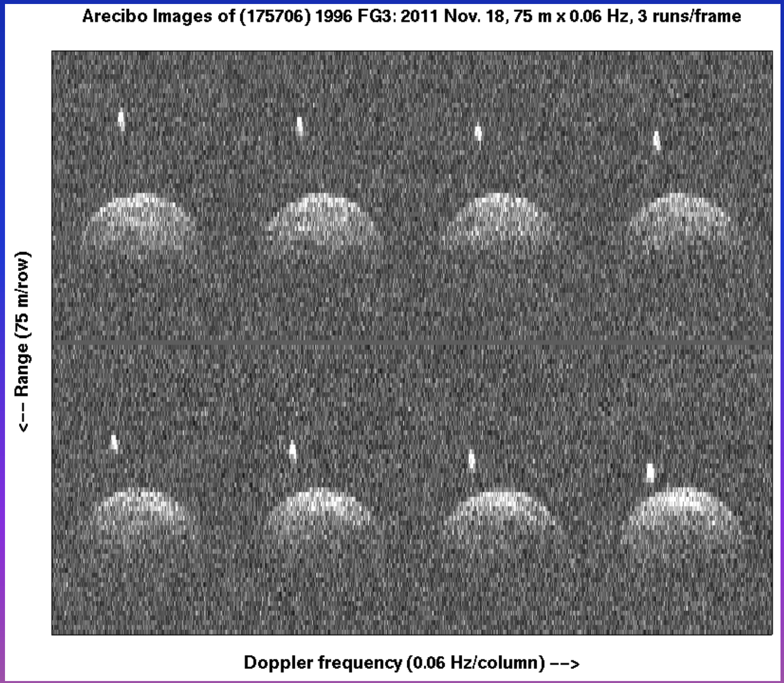
Dimensions

Primary Diameter ~ 1.9 km
Secondary Diameter ~ 0.5 km

Radar cross section: $0.45\ km^2$ +- 35% (X-band)
Radar albedo: 0.16 +- at least 35%



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More *Preliminary* Results

Maximum separation	= 2.55 km (on Nov. 22)
Subradar latitude	= 16 deg
-> Mass	~ 3 E12 kg
-> Density	~ 0.9 g/cm^3

CAVEATS:

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

Future Work:

Shape modeling

Orbital parameter and mass estimation

Gravitational slopes

L. Benner Courtesy

Other Selected Physical Properties

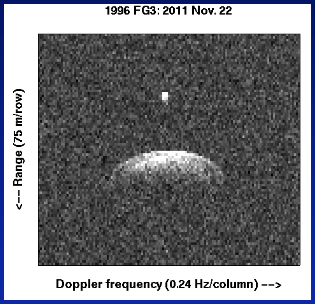
Absolute mag.	H = 18.005	JPL/Horizons
	H = 17.76+-0.03	Pravec et al. 2006
Spectral class:C		Bus and Binzel 2002
Albedo	p_V = 0.029+0.026-0.012	Mueller et al. 2011

Binary system: (Pravec et al. 2006)

Primary Period	P = 3.5942 +-0.0001 h	
Secondary orbital period	P = 16.14 h	synchronous

1996FG3 in the 3-µm region

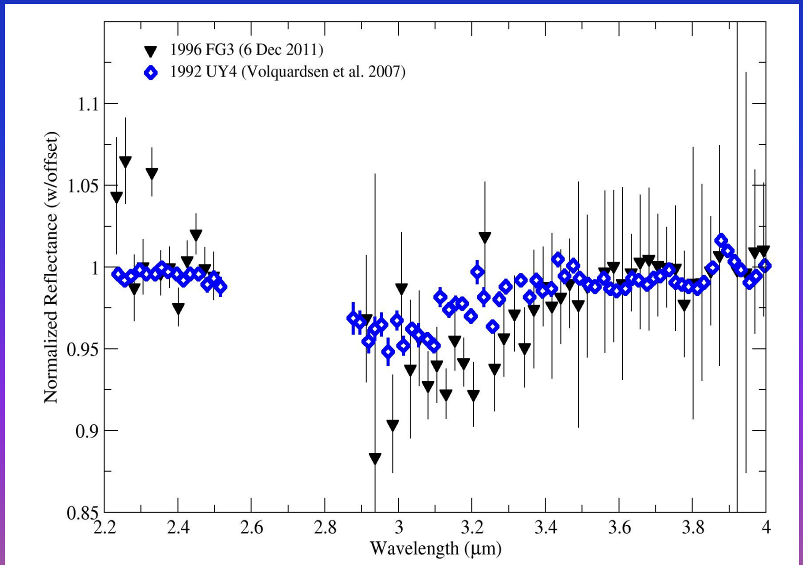
- **Only second NEO found with a 3-µm band**
- 6 Dec data best
  - 20 Nov data too high phase for this thermal model
  - 24 Dec data consistent but rattier



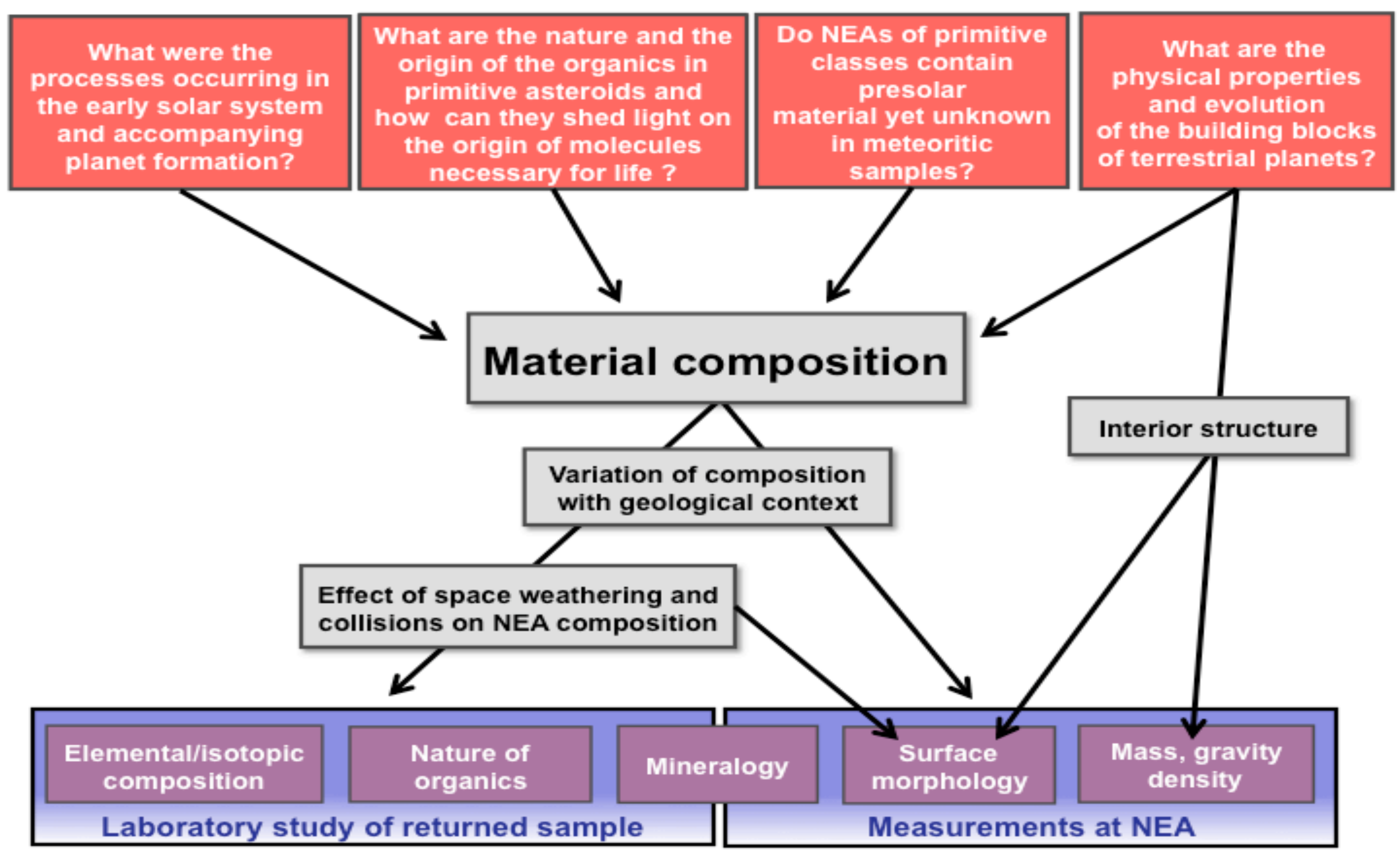
- **Band of ~5-10%, consistent with band shapes in meteorites, Pallas-types**
  - **Band depth dependent upon exact thermal correction**

From A. Rivkin et al.

- **Interpreted as hydrated/hydroxylated**



MarcoPolo-R will provide insights…



MarcoPolo-R Science

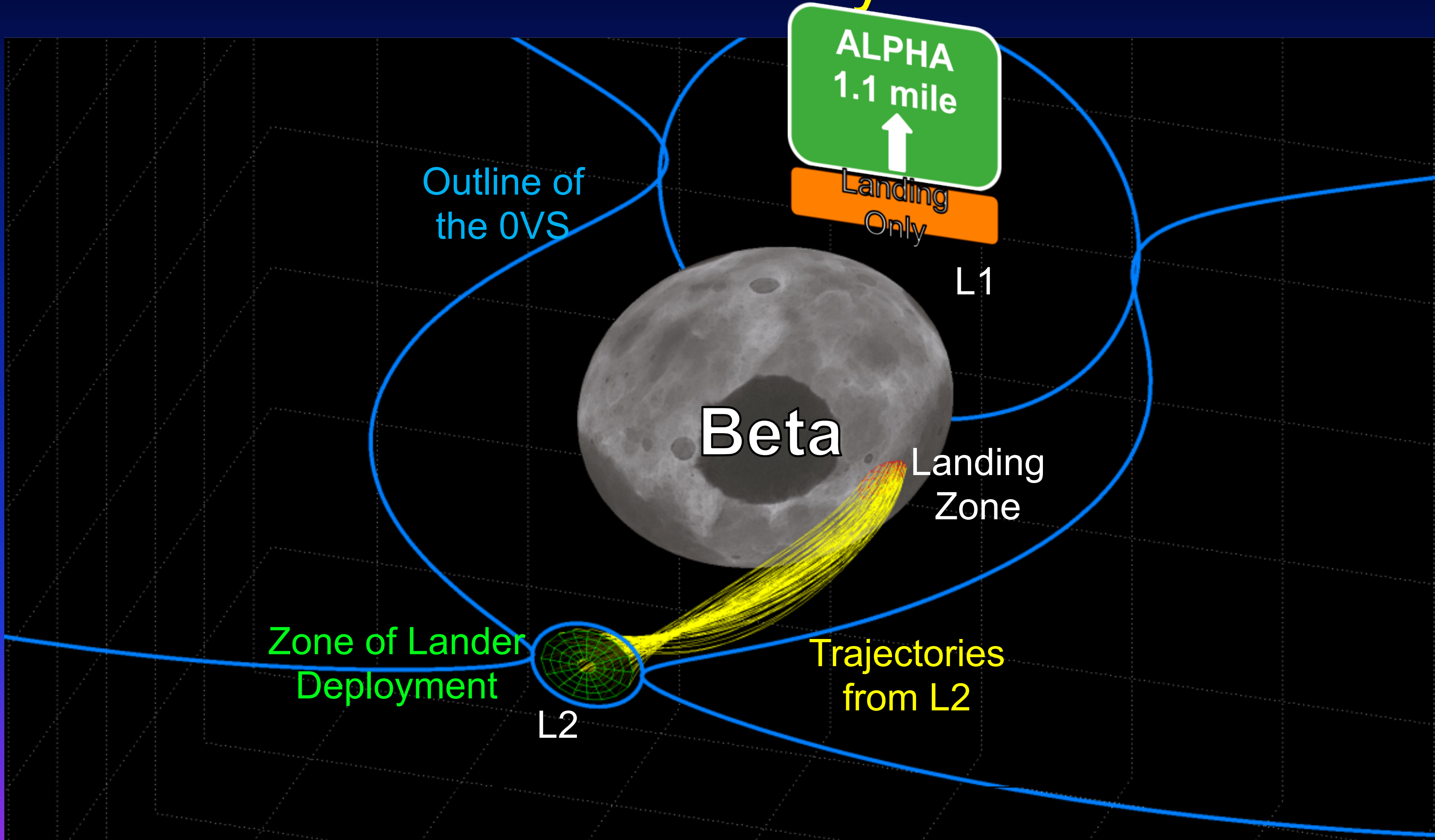
Baseline Science Payload

	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

Lander Deployment: very easy on the secondary!

STRATEGY DESIGN

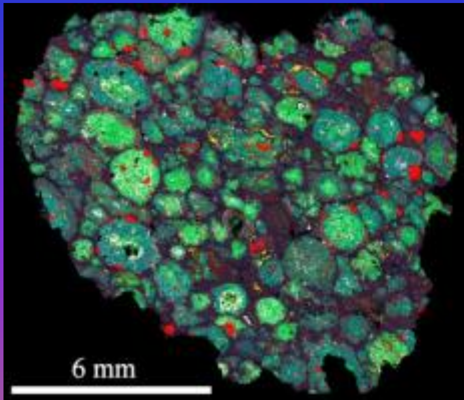


Simon Tardivel Courtesy

Laboratory investigation of returned samples

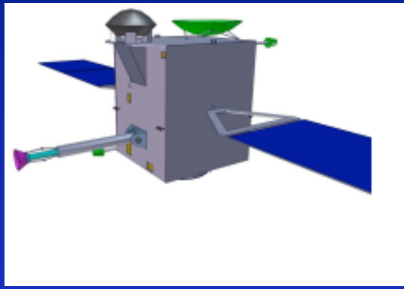
High spatial resolution and analytical precision are needed:

- **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**



Baseline mission

Target: 1996 FG3, several months stay time
Launch window: 2021/2023 and sample return in 2029
Soyuz Fregat launcher, electric propulsion, direct interplanetry Escape; industrial studies started in Feb. 2012 until summer 2013

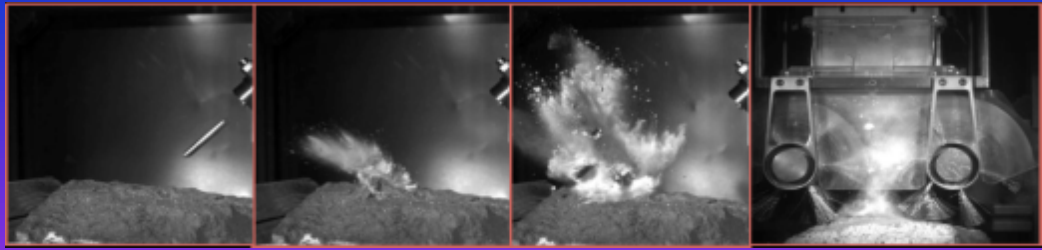


Single primary spacecraft, carrying:

- Earth Re-rentry Capsule (ERC)
- Sample acquisition and transfer system (SAS)

Touch and go sampling mechanisms (non-exhaustive list):

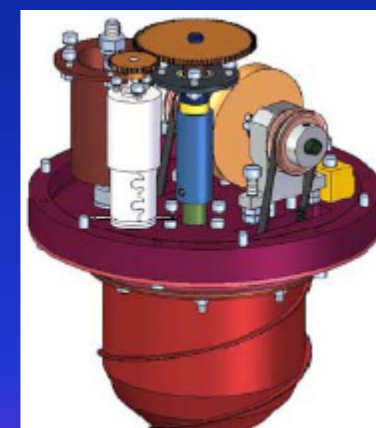
- Brush or cutting wheels
- Corers
- Gaseous transport devices



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

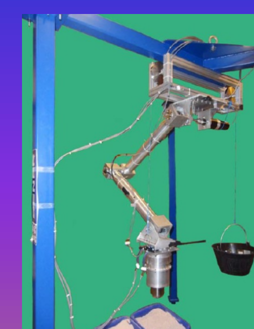
Sampling - technology

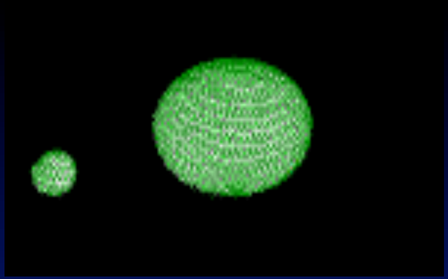
1. SENER company + Comet Nucleus Sample Return (CNSR) activities in the 90’s → corer works!!
   a. Systematically collected over 50 grams
   b. Forces and torques within the specifications
   c. Very simple system
2. Other activity by Astrium internal R&D: looked at a different concept



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**





In summary

- The different models of binary formation imply different internal and surface structures of the components: MarcoPolo-R will allow us to discriminate between these models!
- All scenarii imply that the progenitor is low-strength and not perfectly monolithic: MarcoPolo-R will allow us to check this (mechanical properties of the sample, bulk density and gravitational potential of the primary)!
- A mission to a binary allows investigating the fascinating geology and surface processes at work in a low-g environment!
- The space investigation of a binary allows the deployment of a lander on the secondary with minimal effort and risk!

A sample return from a binary, in addition to the science of primitive materials, will allow us to test these scenarios and their implications on the physical properties of small bodies

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

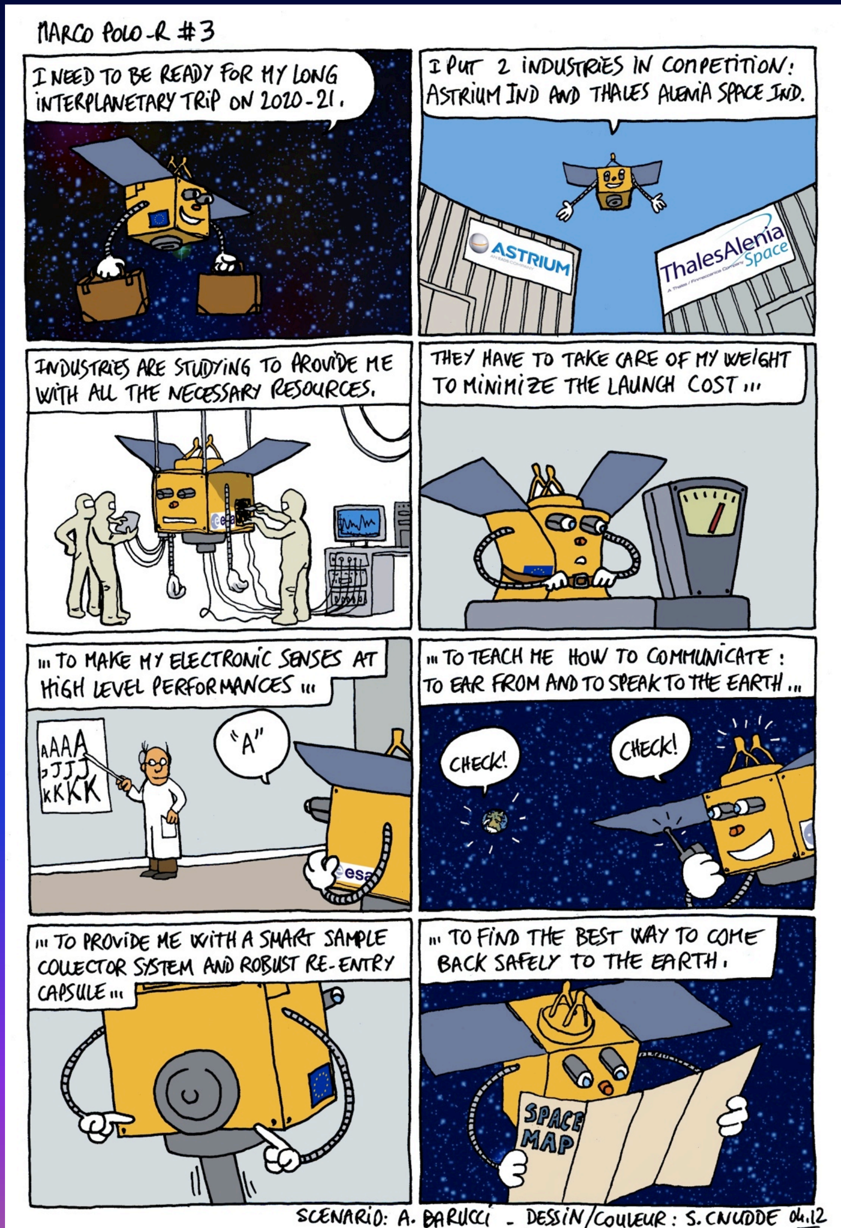
- ✓ provide a unique window into the distant past
- ✓ allow scientists to unravel mysteries surrounding the birth and evolution of the solar system
- ✓ involve a large community, in a wide range of disciplines

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 2012), 25 countries

Join us!!

International collaboration is open

Next Workshop and Symposium:

- **Paris (CNES HQ), Dec. 17-18, 2012: Cosmochemistry Workshop**
- **Barcelona (Spain), Jan. 16-17 2013: 4th MarcoPolo-R Symposium**

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