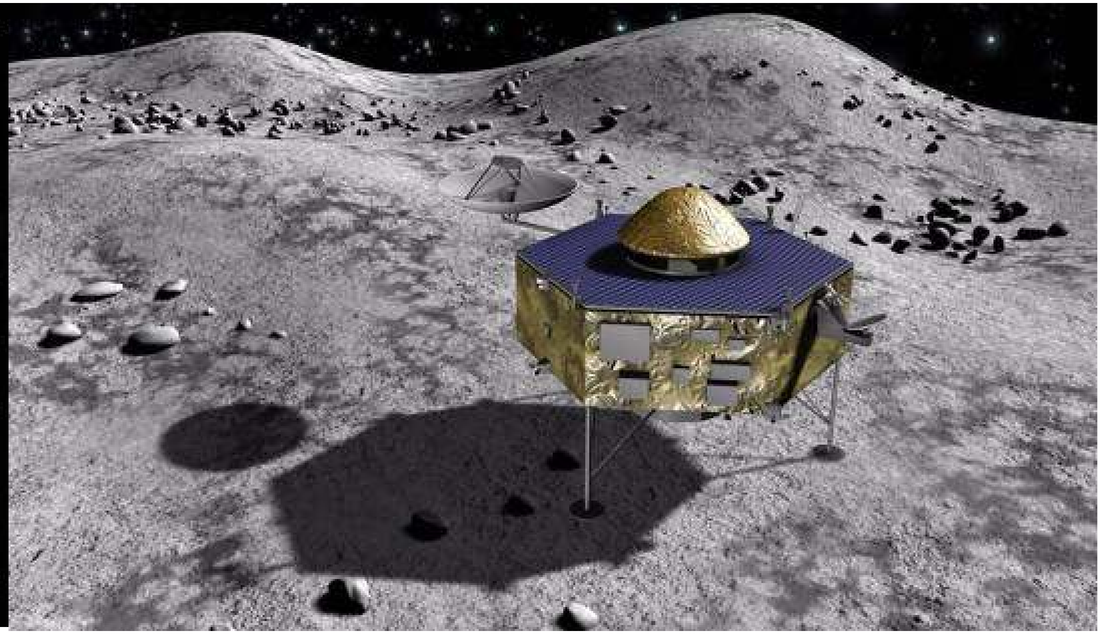
MARCO POLO

Near Earth Asteroid Sample Return Mission



Science Study Team:
M.A. Barucci (F), H. Boehnhardt (D), J.R. Brucato (I), E. Dotto (I), I.A. Franchi (UK), S.F. Green (UK), J.-L. Josset (CH), P. Michel (F), K. Muinonen (FIN), J. Oberst (D), R. Binzel (MIT, USA), M. Yoshikawa, J. Kawaguchi, H. Yano (JSPEC/JAXA, J)
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:

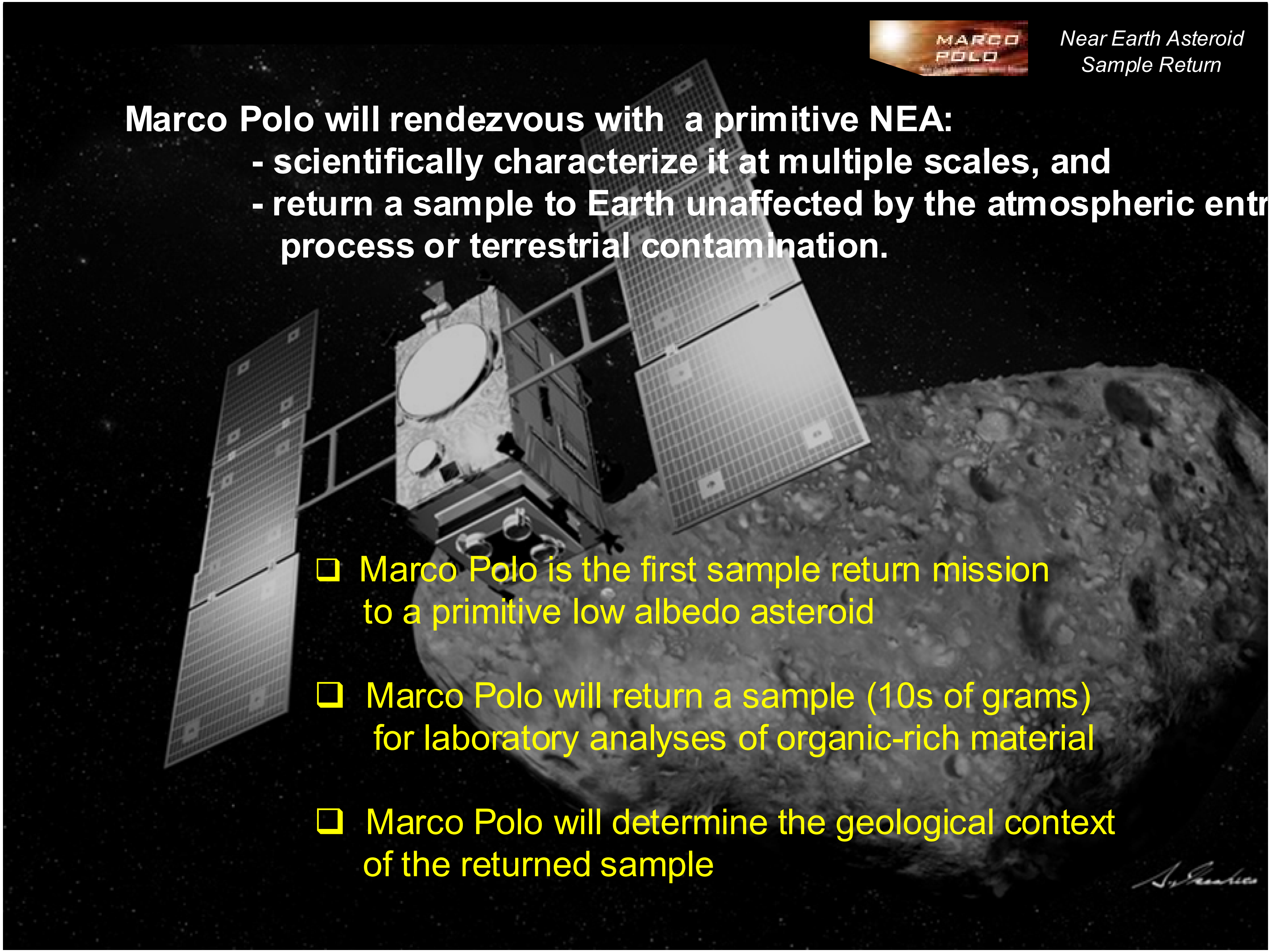
SALMON (Stand Alone Missions of Opportunity):

hardware & software components

Marco Polo will rendezvous with a primitive NEA:

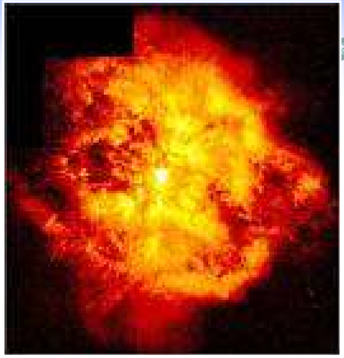
- scientifically characterize it at multiple scales, and

- return a sample to Earth unaffected by the atmospheric entr process or terrestrial contamination.

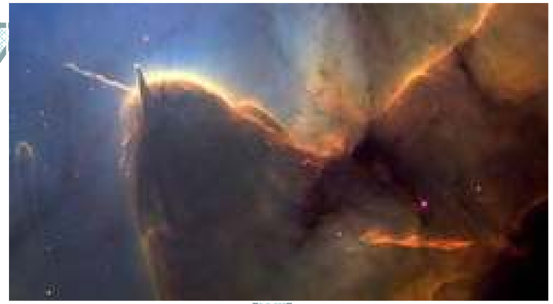


- Marco Polo is the first sample return mission to a primitive low albedo asteroid
- Marco Polo will return a sample (10s of grams) for laboratory analyses of organic-rich material
- Marco Polo will determine the geological context of the returned sample

Marco Polo addresses a wide range of objectives



Stars
Stellar nucleosynthesis
Nature of stellar condensate



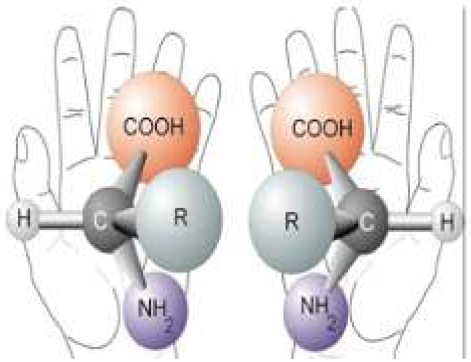
The Interstellar Medium
IS grains, mantles & organics

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

The Earth
Impact hazard
Evolution of life on Earth



Life
Nature of organics in NEOs

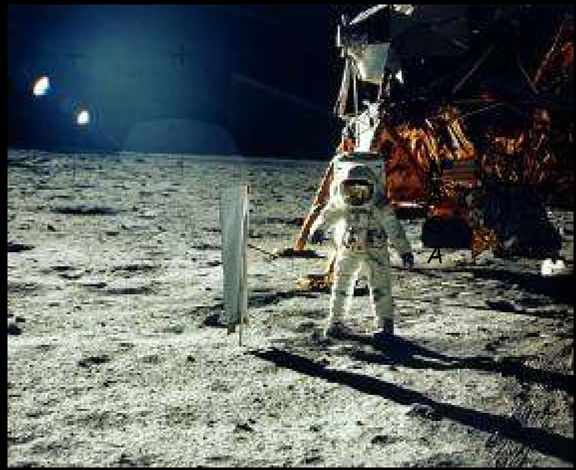

The Solar System formed from a disk of gas and dust
orbiting around the Sun.

Animation

We need to return samples from space

Original material
Formation processes
Chronology

Genesis



Apollo & Luna

Stardust

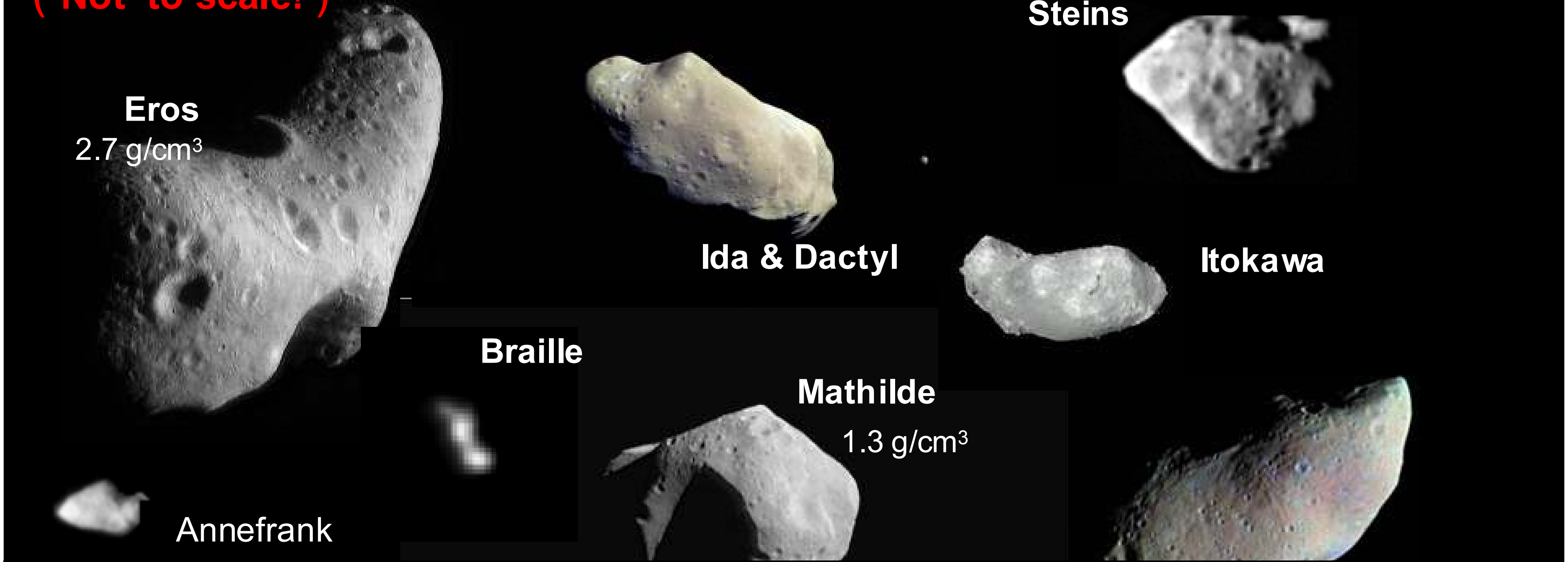
A pristine sample from a primitive asteroid is required to study the precursors of terrestrial planets

Look different, but common origin

Minor Bodies: Asteroids and Comets Visited So Far

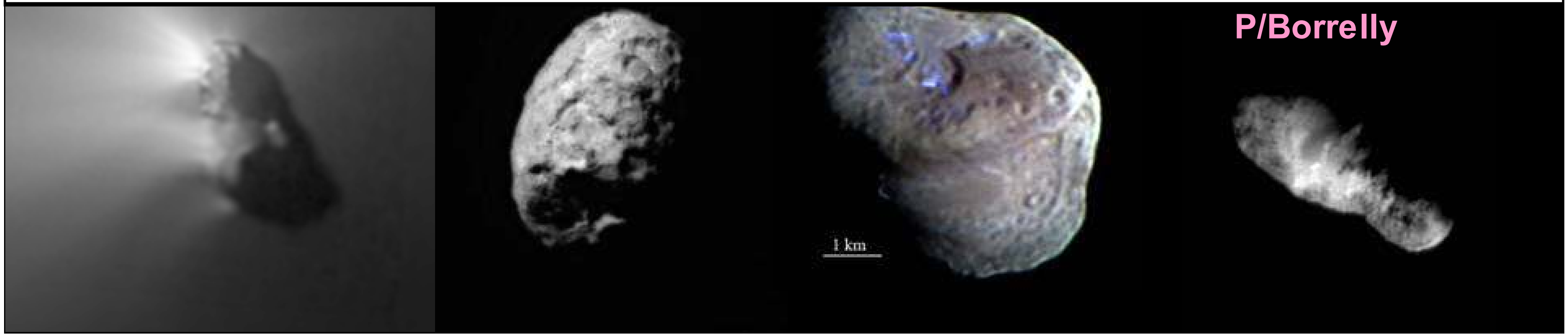
(Not to scale!)

Near Earth Asteroid Sample Return

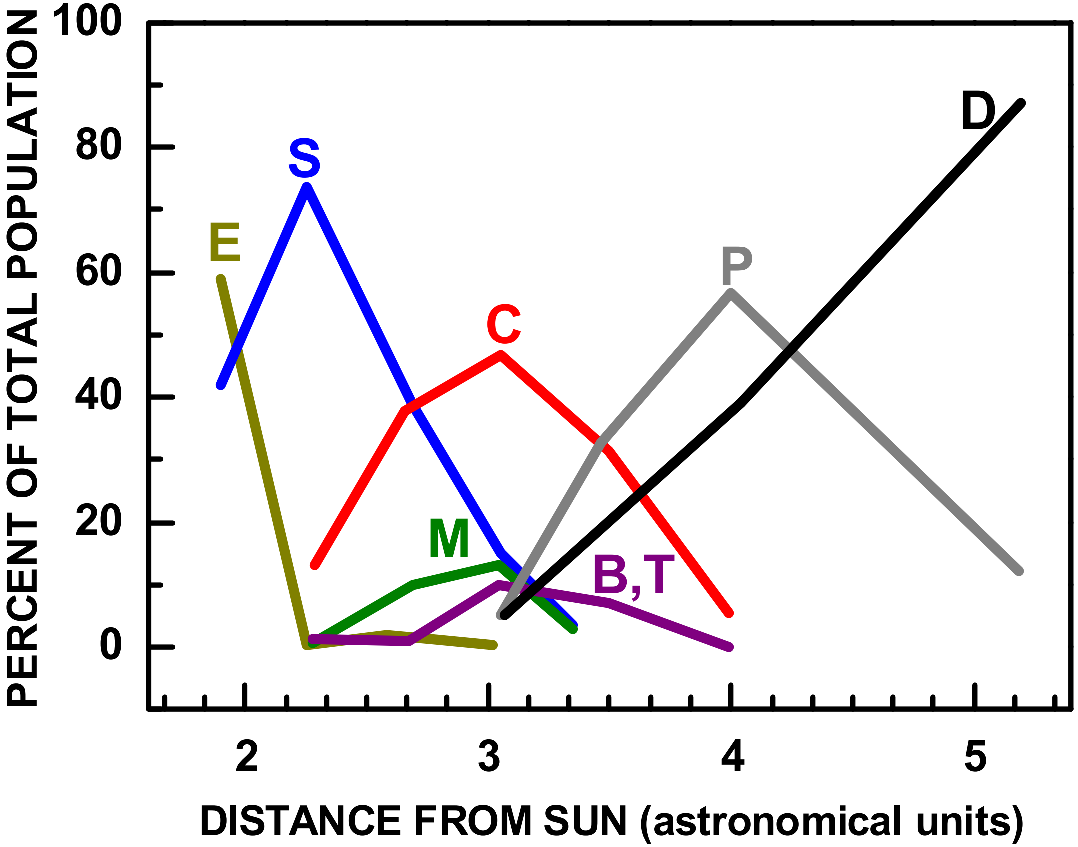


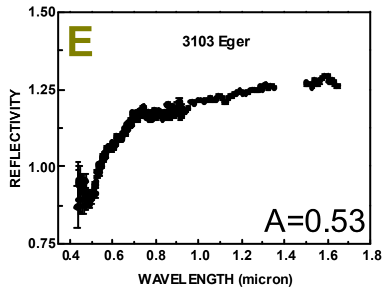
Look different, but common origin.

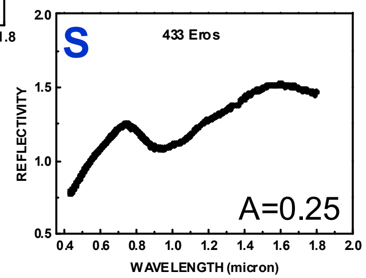
Only primitive types retain a memory of the origin.

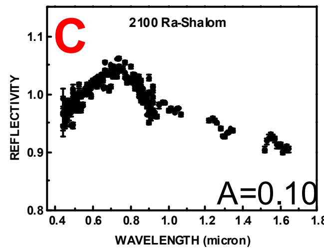


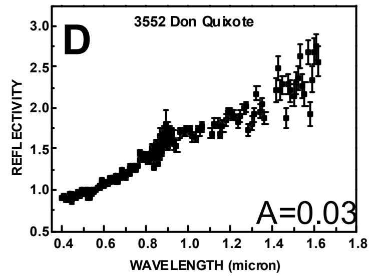
Marco Polo target: dark primitive classes: C, P, D

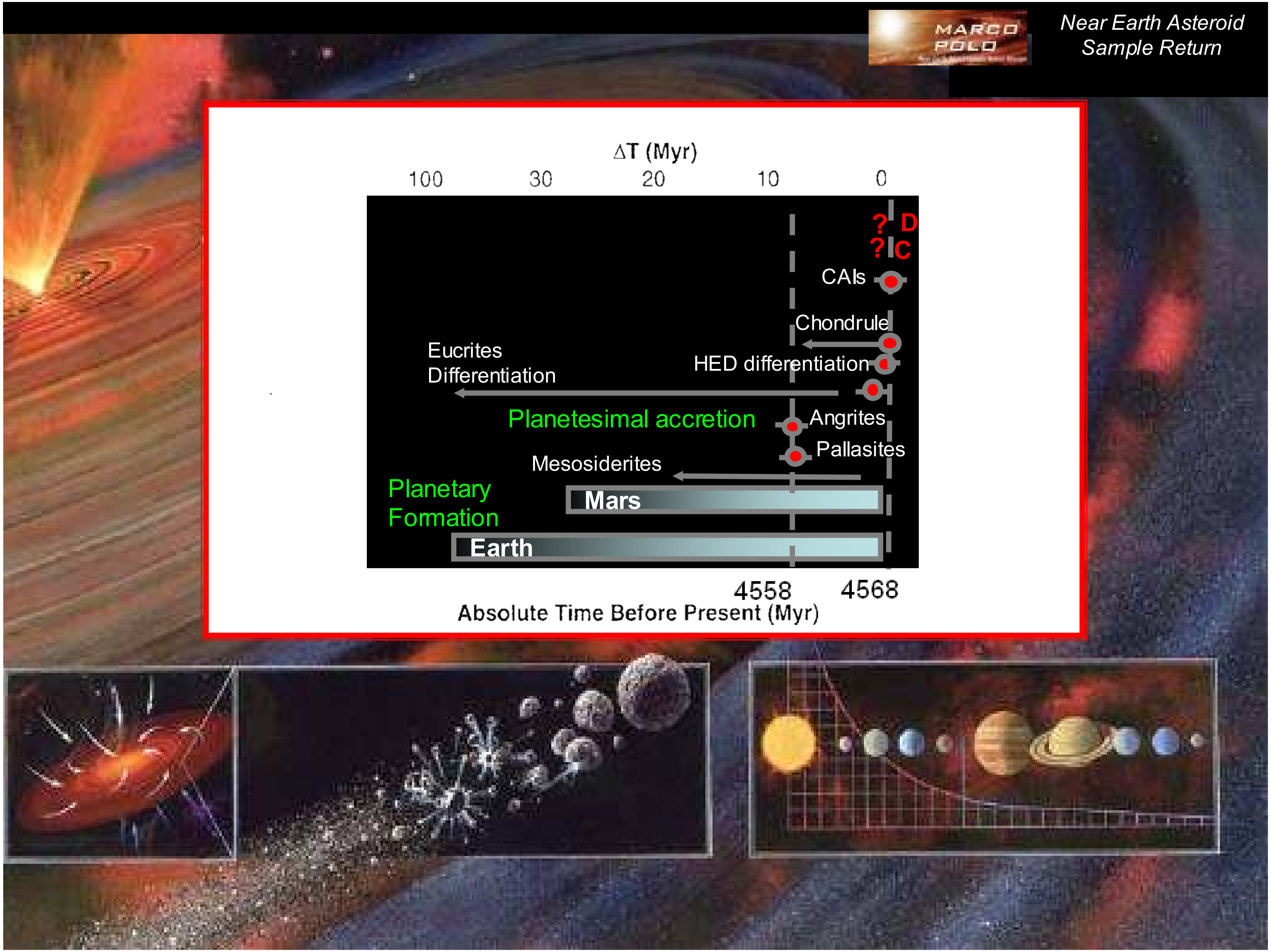








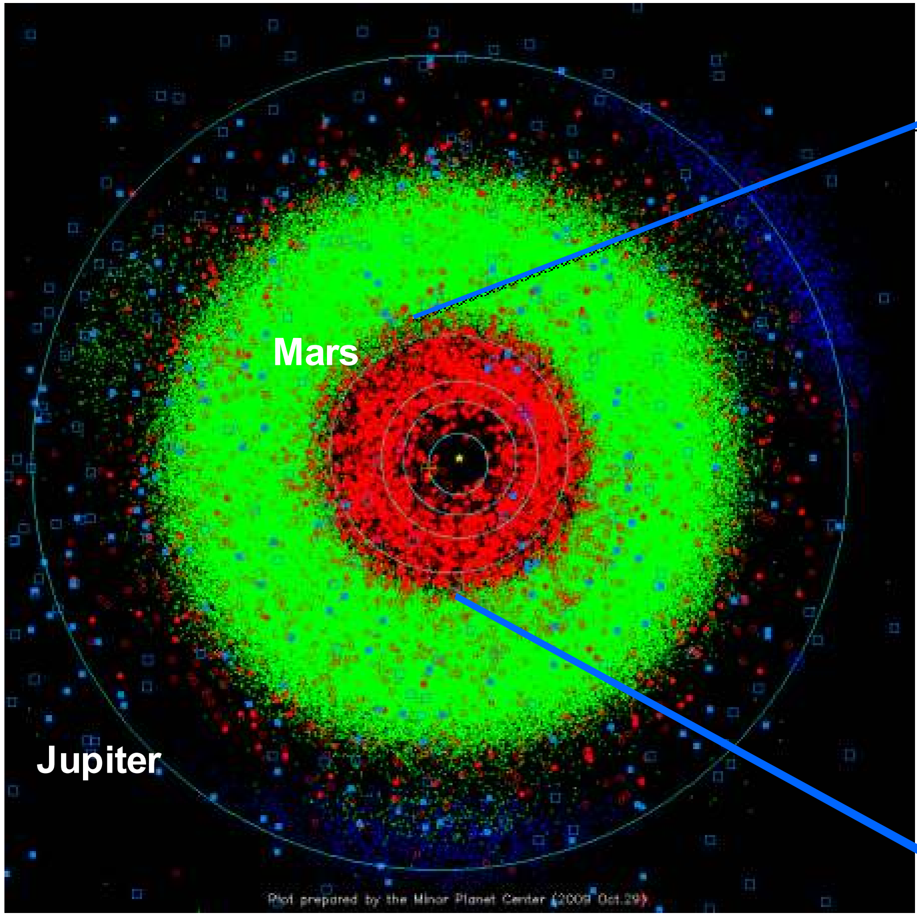


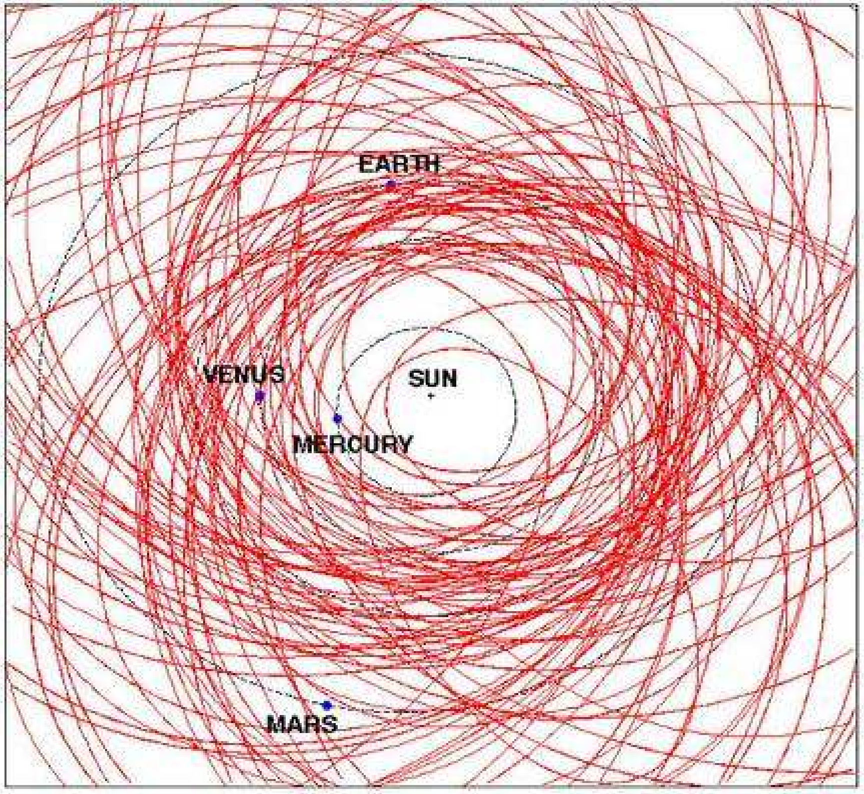


MARCO POLO
Near Earth Asteroid Sample Return
ΔT (Myr)
100
30
20
10
0
? D
? C
CAIs
Chondrule
Eucrites Differentiation
HED differentiation
Planetesimal accretion
Angrites
Pallasites
Mesosiderites
Planetary Formation
Mars
Earth
4558
4568
Absolute Time Before Present (Myr)

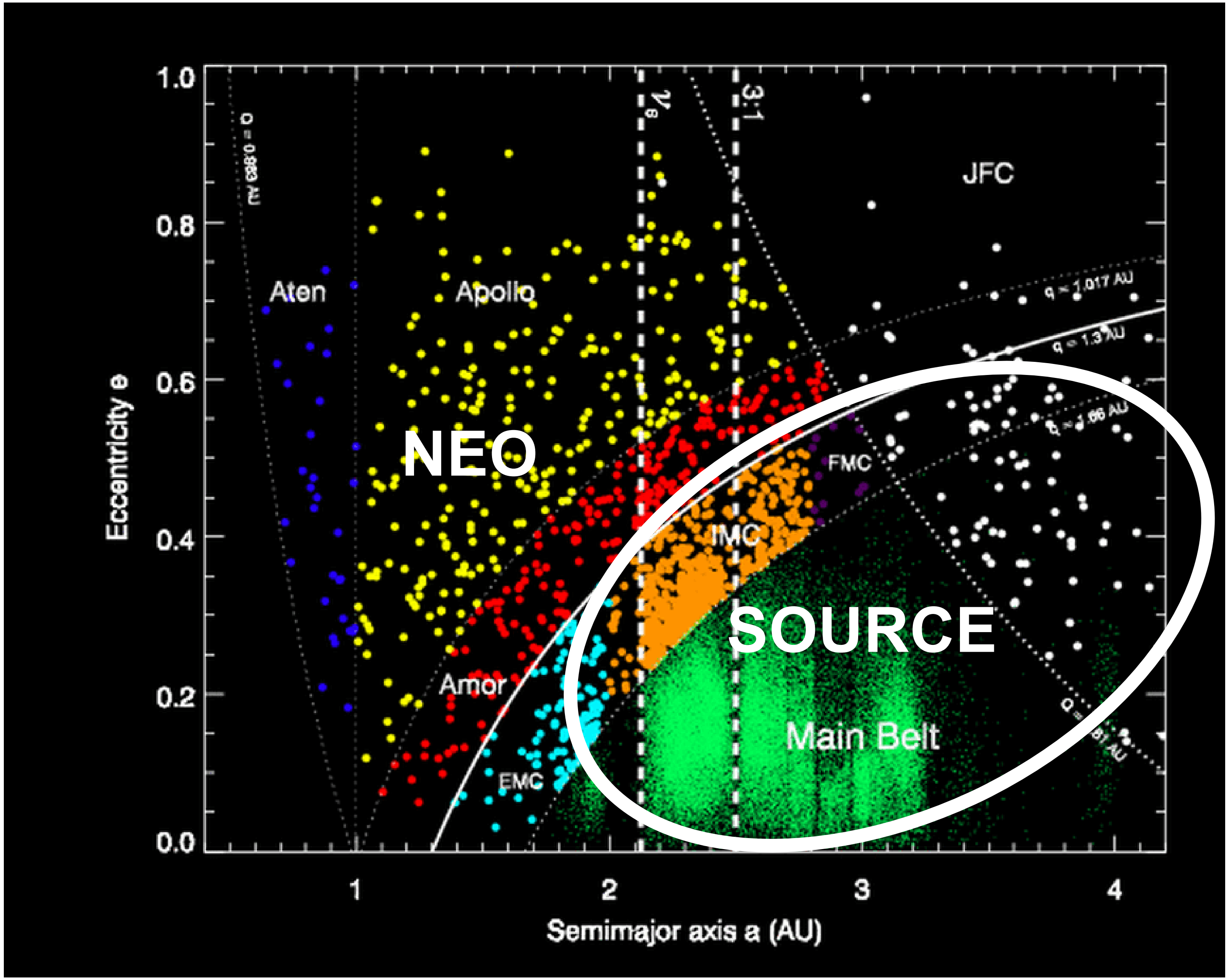
Asteroid population

Near Earth Asteroids

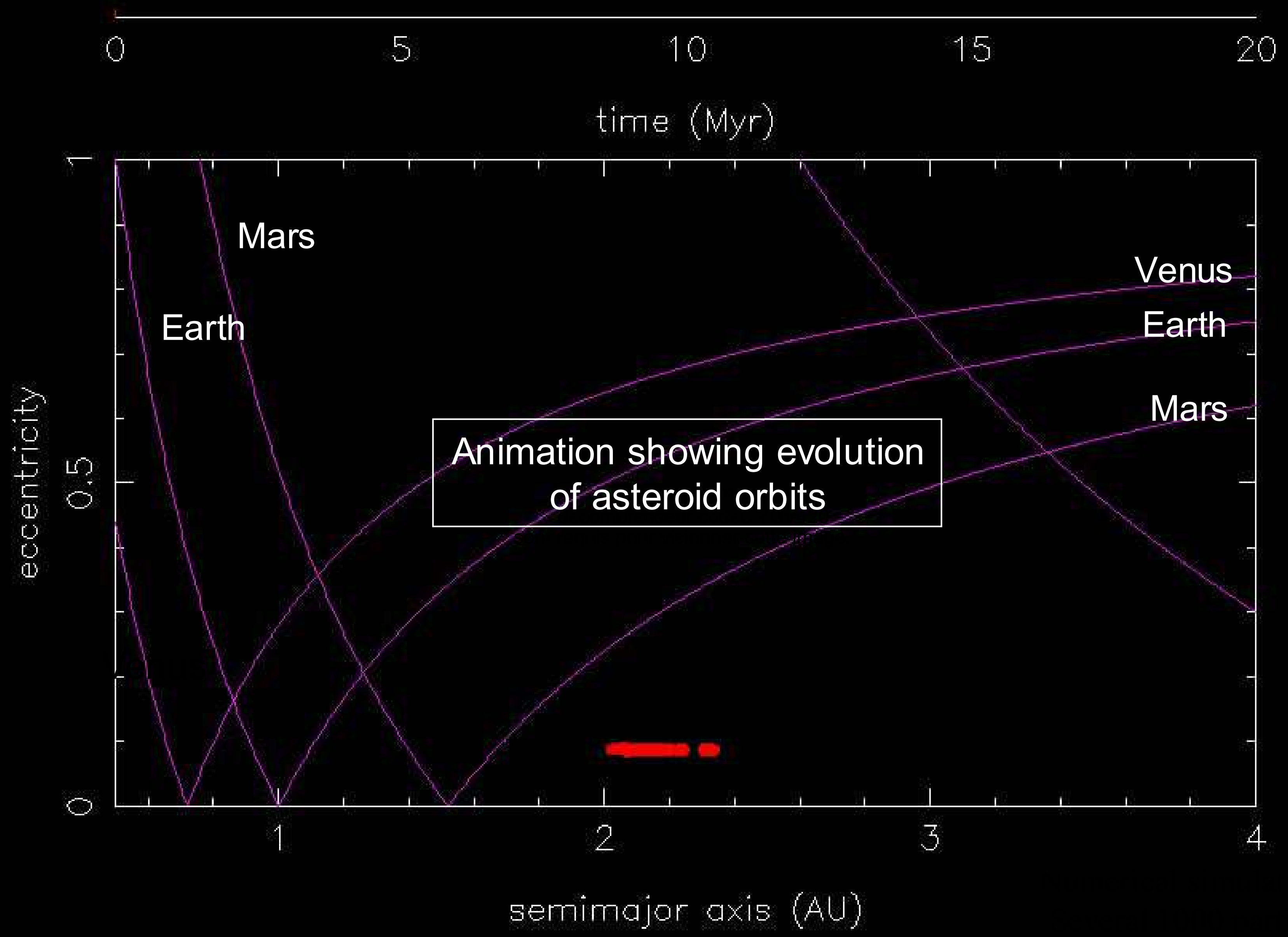




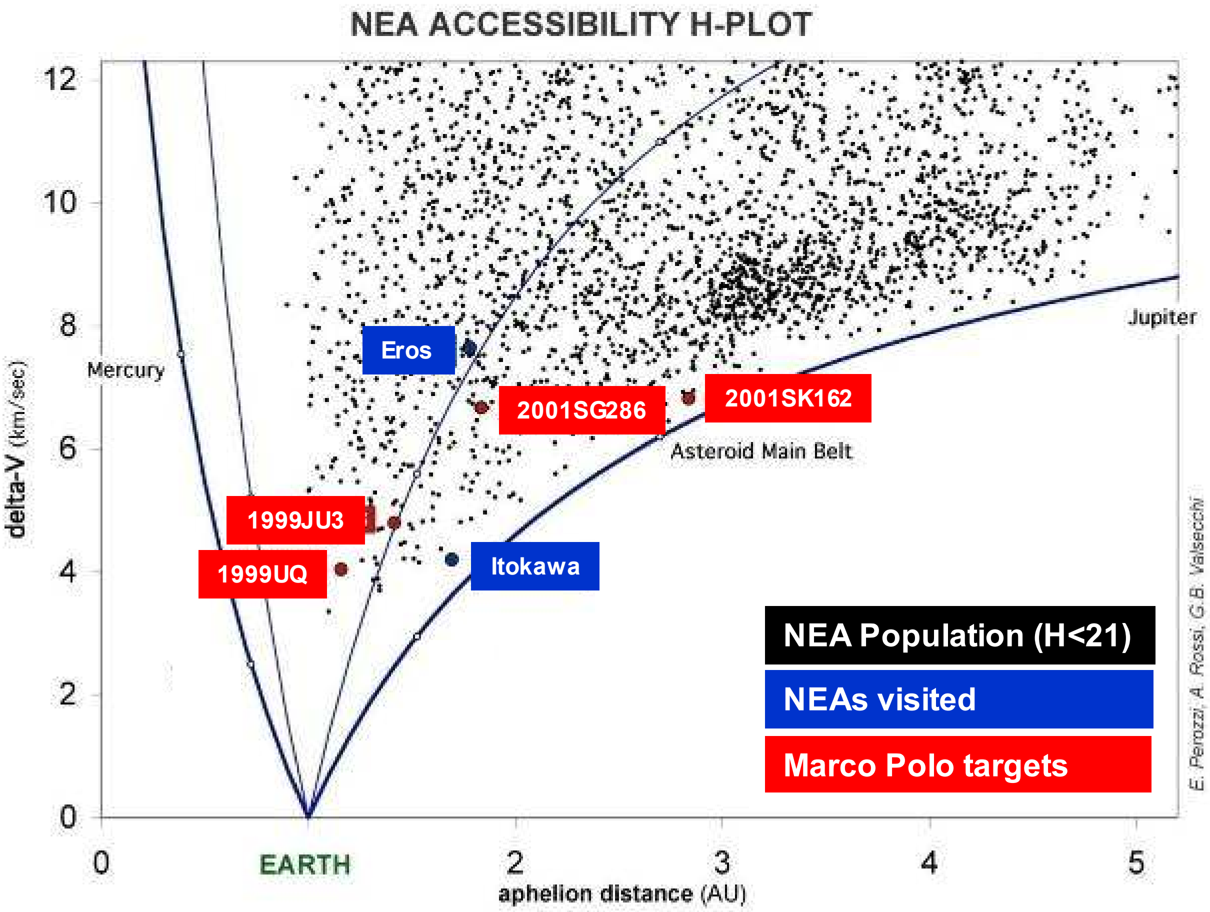
More than 6000 known NEOs



Fast resonances: **Main Belt Asteroids become rapidly NEAs by dynamical transport from a source region (in a few million years)**



Why an NEA?



1999 JU3: C class, 0.92 km

NEAs offer many advantages:

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

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

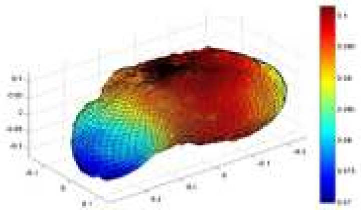
B. Define the processes affecting the gas and the dust in the solar nebula

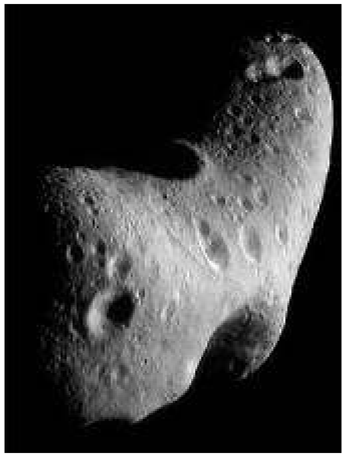
C. Determine the timescales of solar nebula processes

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?


Gravity Map (Modell-A)



D. Determine the global physical properties of an NEA

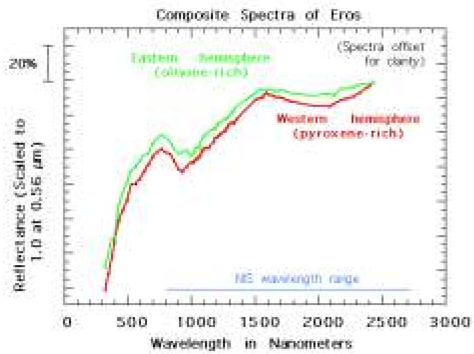
E. Determine the physical processes, and their chronology, that shaped the surface structure

F. Characterise the chemical processes that shaped the NEA composition (*e.g.* volatiles, water)

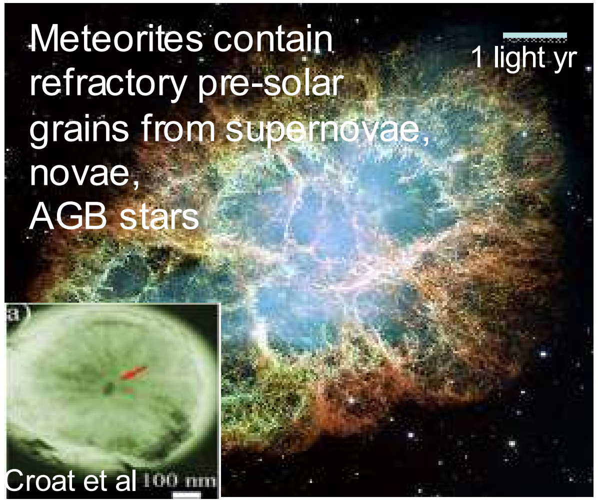
G. Link the detailed orbital and laboratory characterisation to meteorites and IDPs and provide ground truth for the astronomical database

Measurements

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



Do NEAs of primitive classes contain pre-solar material yet unknown in meteoritic samples?

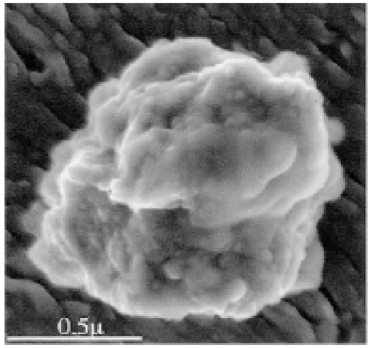


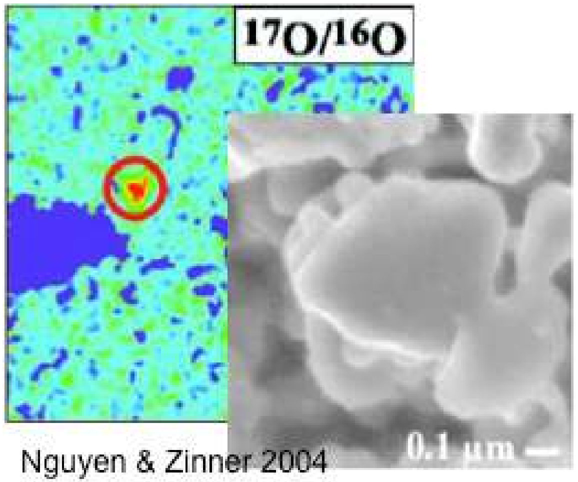
Croat et al

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





Nguyen & Zinner 2004

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

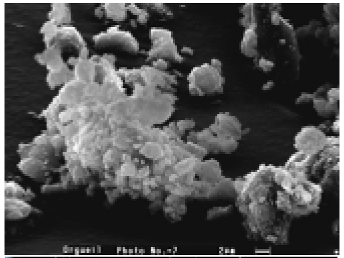
Animation showing transport of organics to Earth

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?



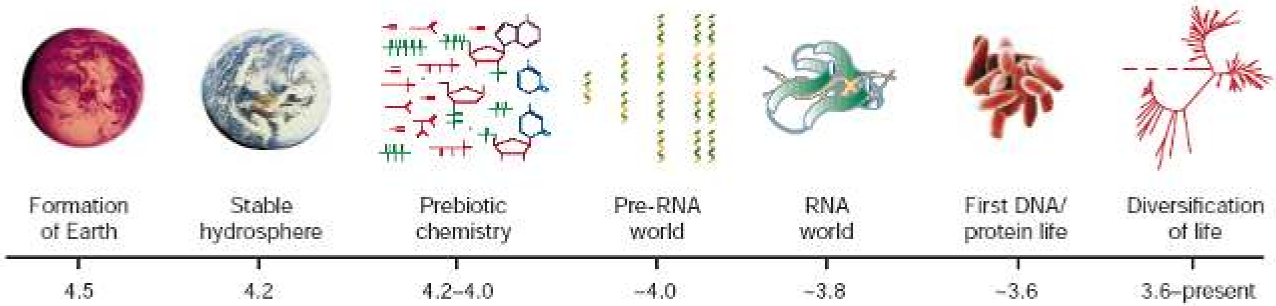
K. Determine the diversity and complexity of organic species in a primitive asteroid

L. Understand the origin of organic species

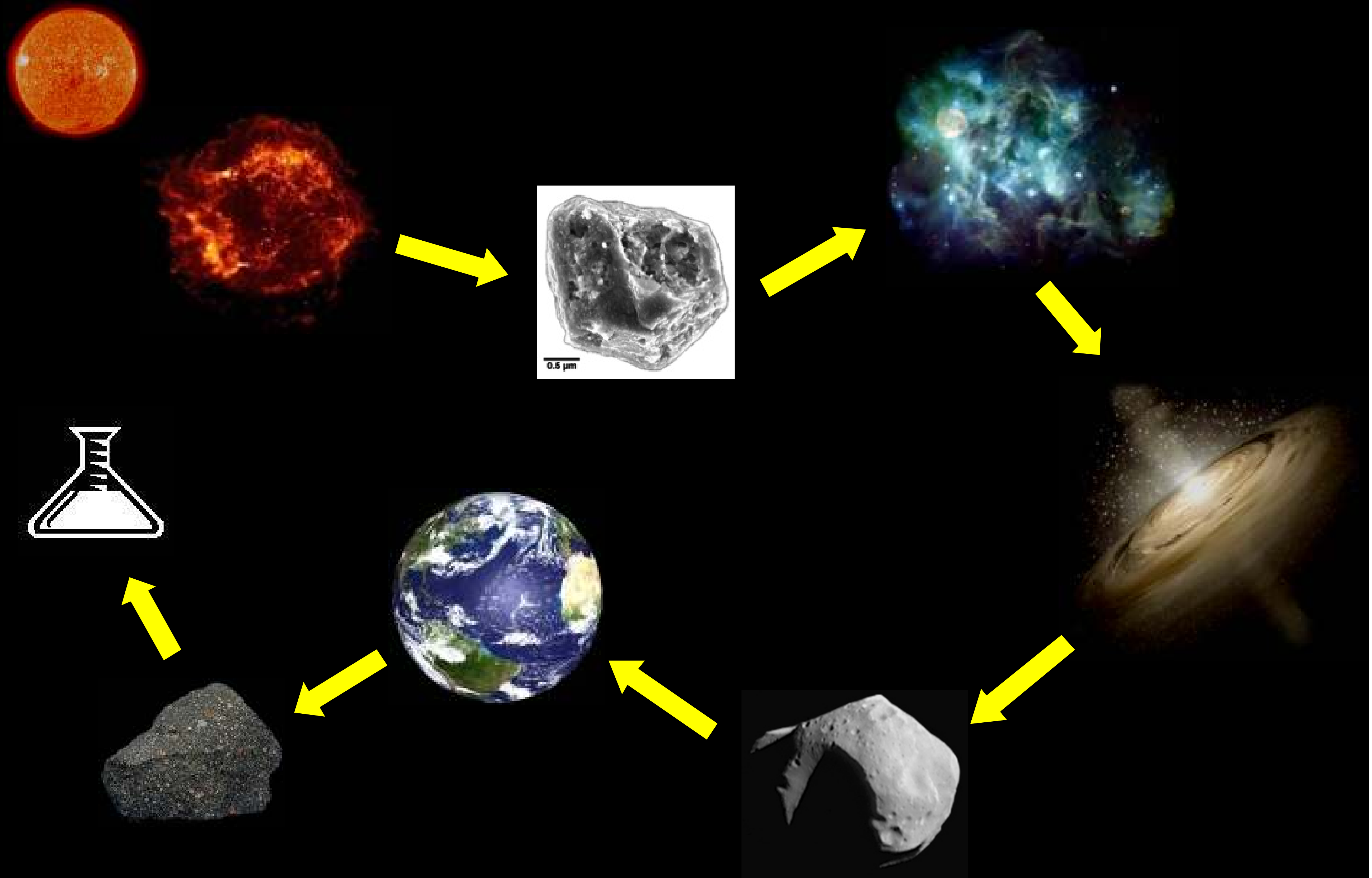
M. Provide insight into the role of organics in life formation

Measurements

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



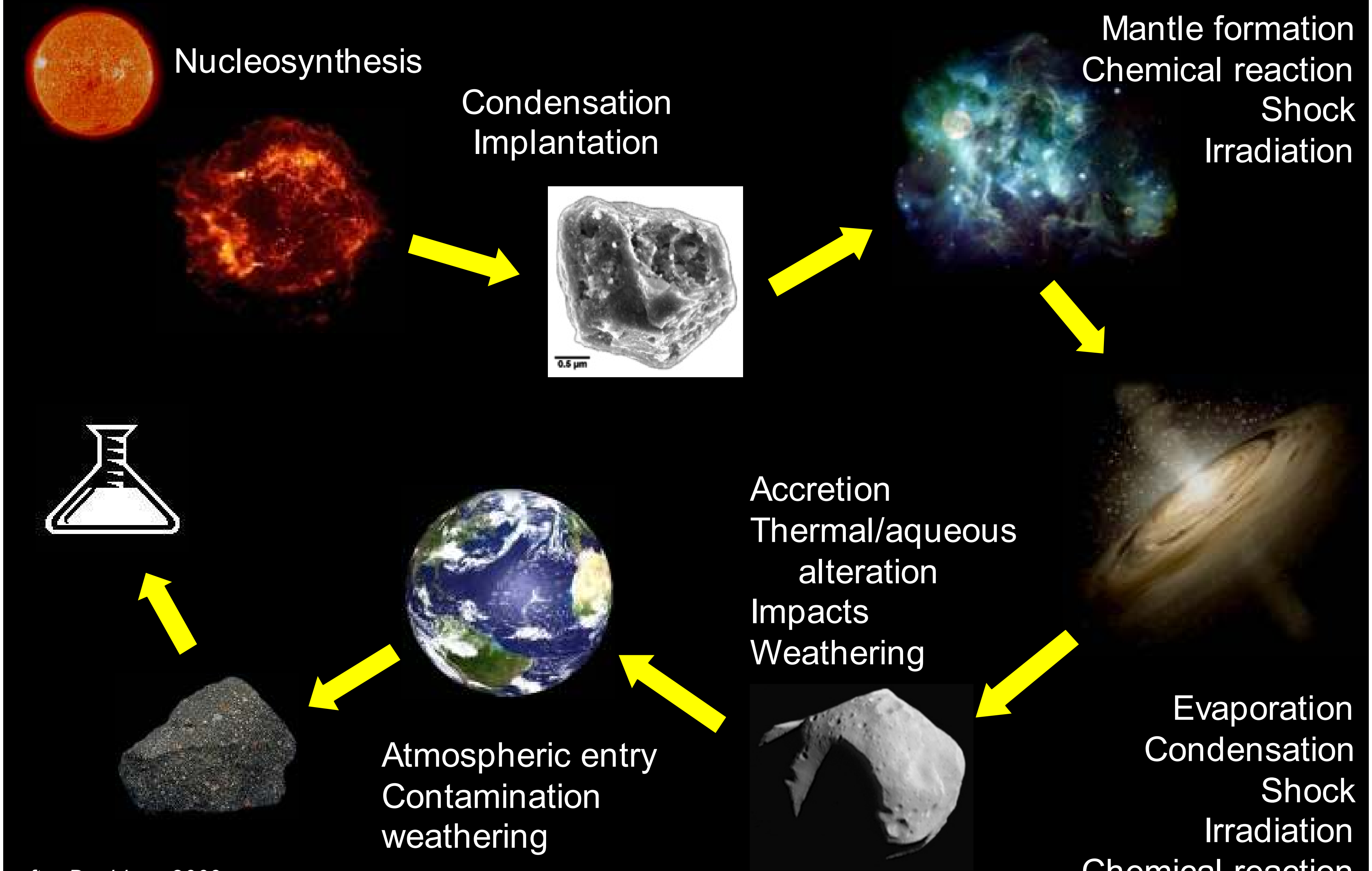
From stars to meteorites



after *Davidson 2009*

Near Earth Asteroid
Sample Return

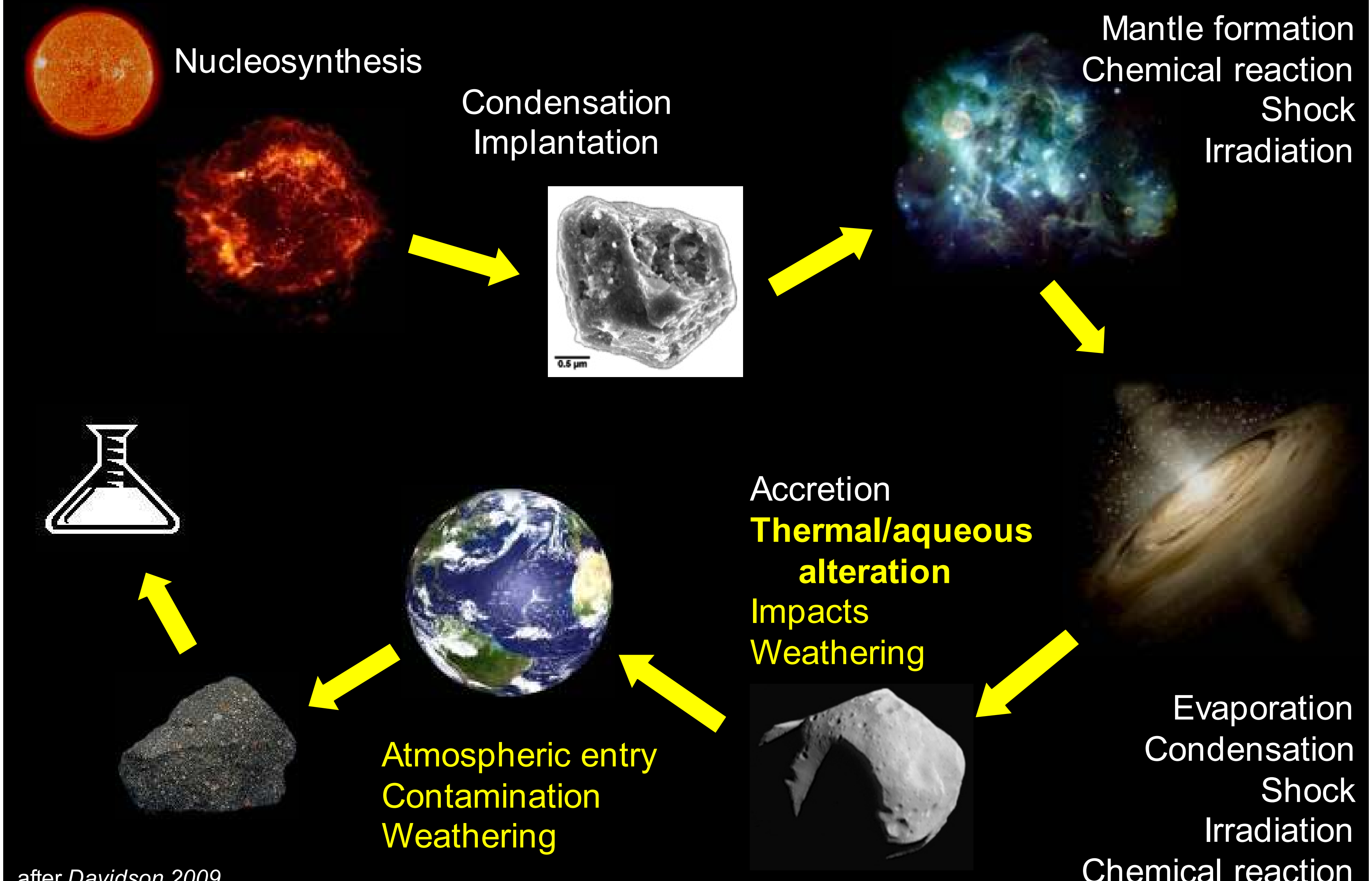
From stars to meteorites



after *Davidson 2009*

Near Earth Asteroid Sample Return

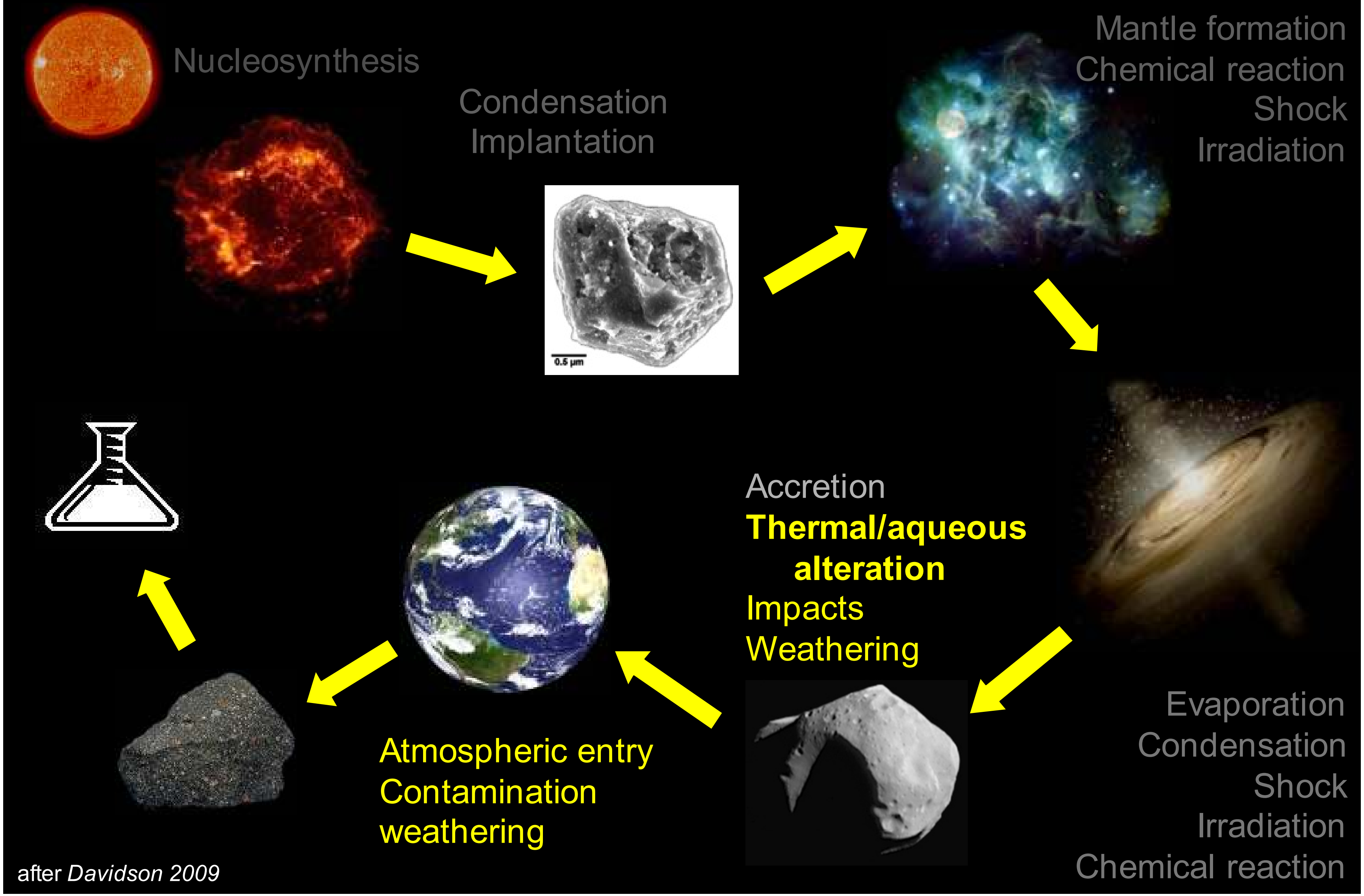
From stars to meteorites



after *Davidson 2009*

From stars to meteorites

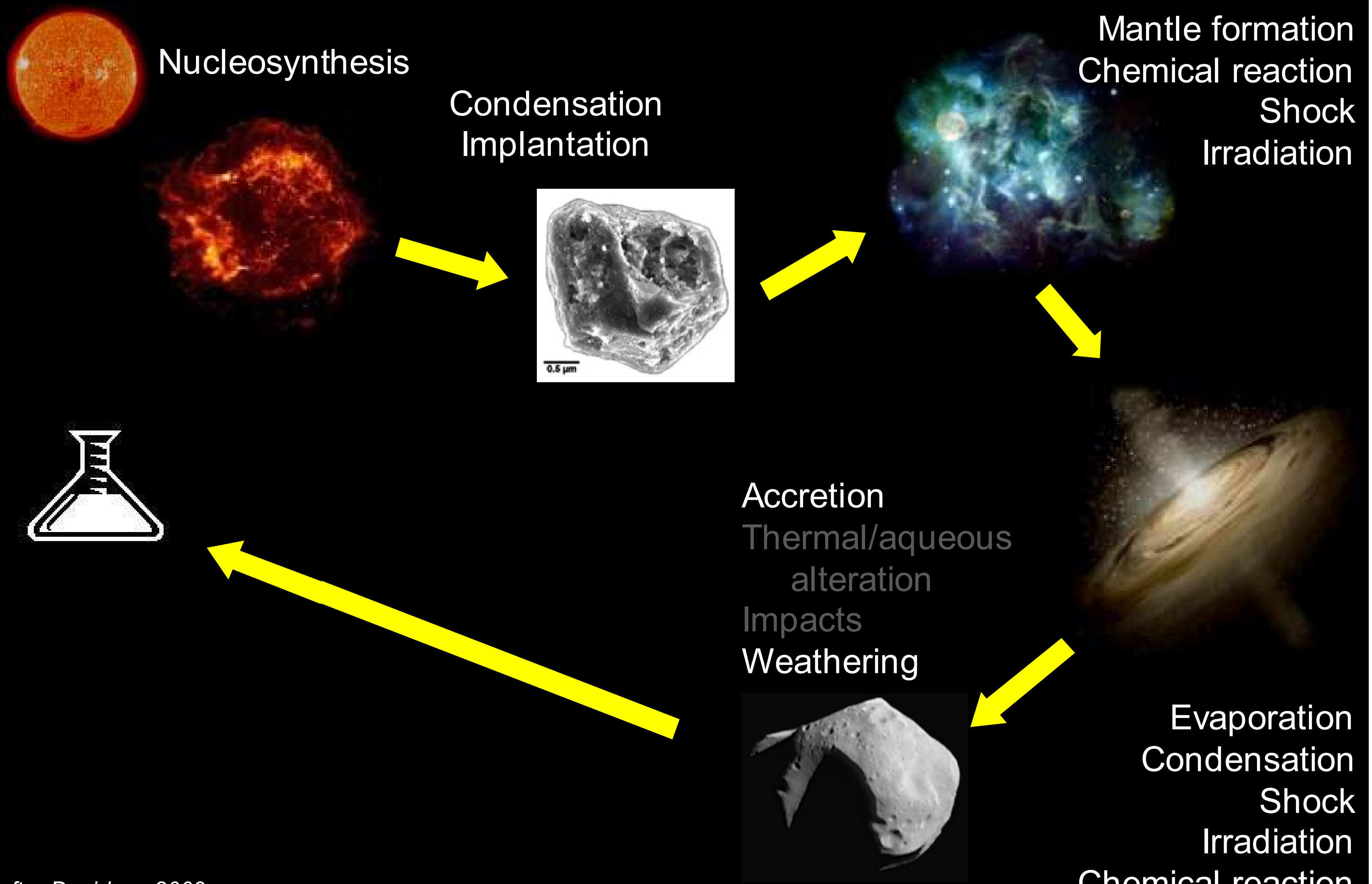
Near Earth Asteroid Sample Return



after *Davidson 2009*

From stars to meteorites

Near Earth Asteroid Sample Return

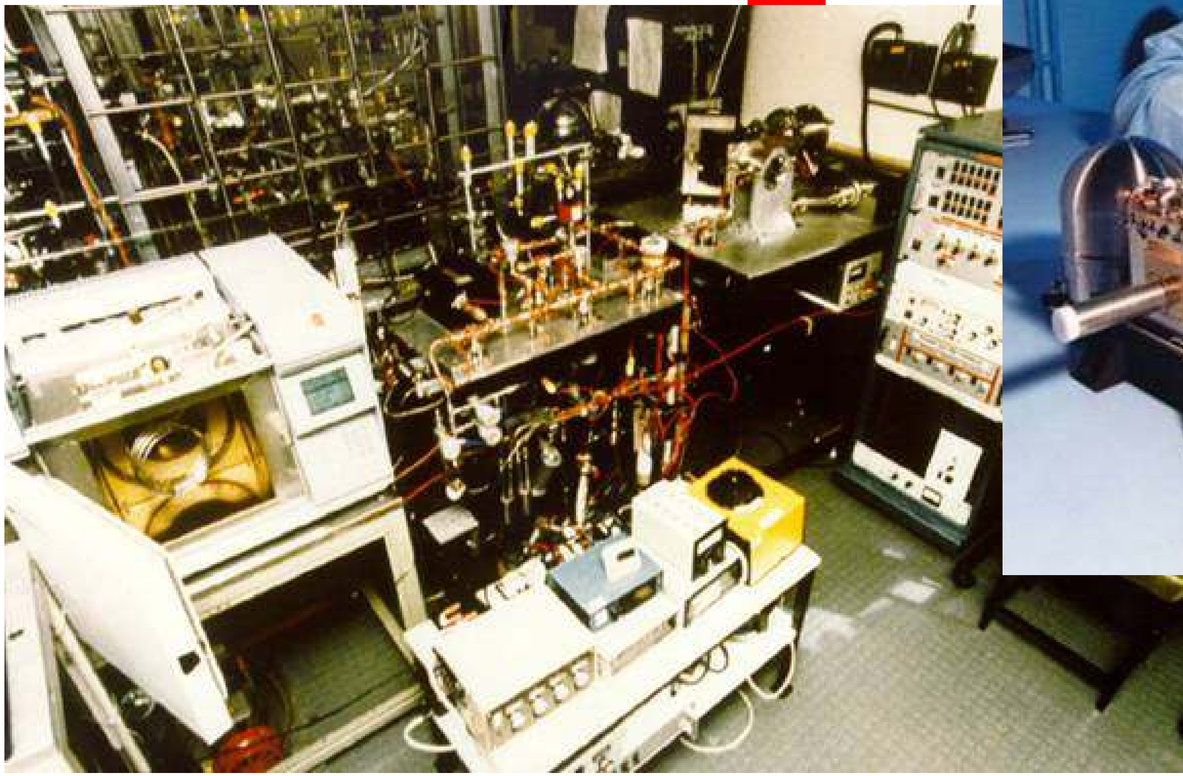


after *Davidson 2009*

“Why do you need to *return* samples?”

Superior instruments…

"Miranda" GC-IRMS
Laboratory
Isotope ratio ± 0.01%



Rosetta Ptolemy
In situ
Isotope ratio ± 1%

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

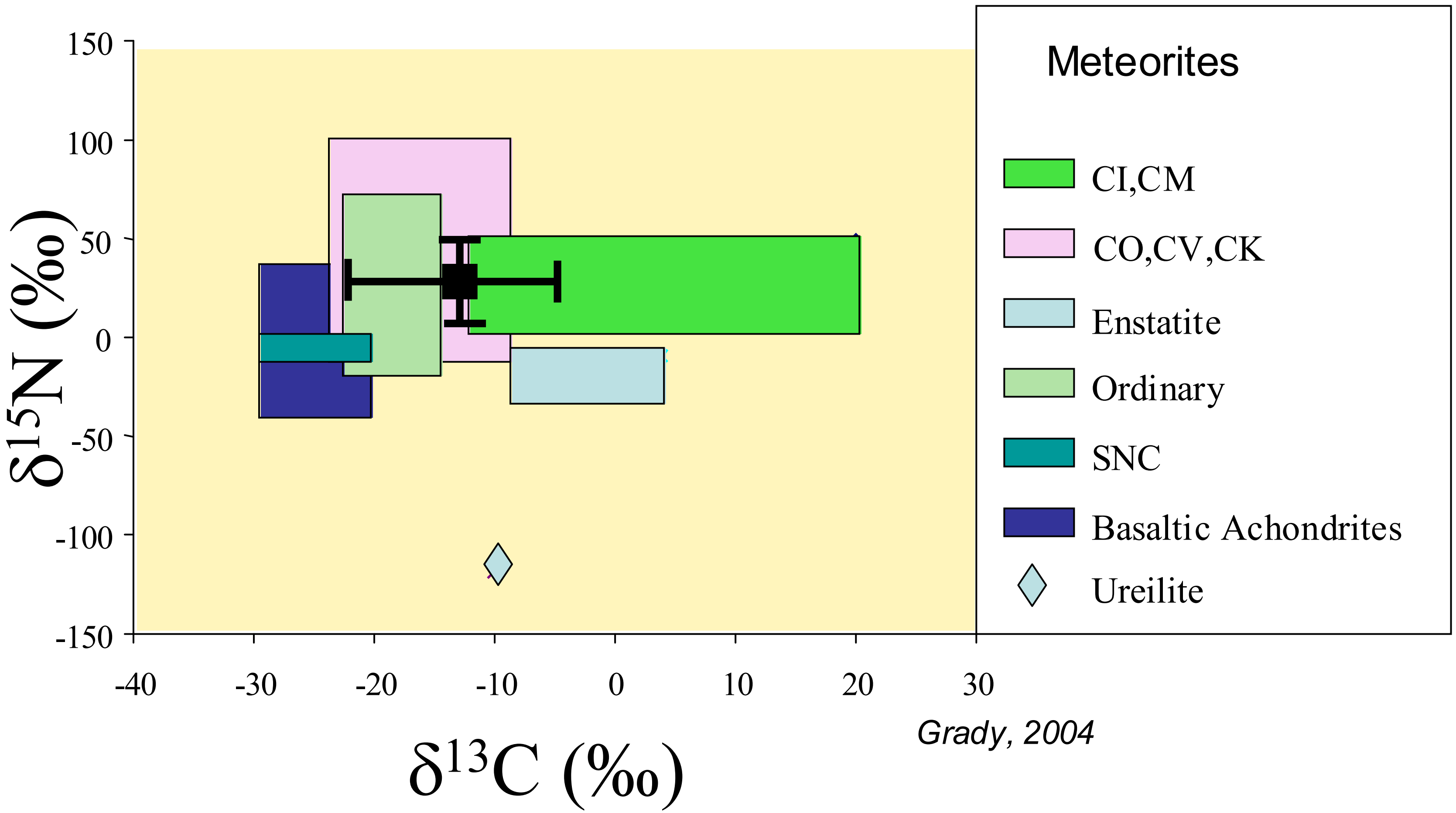
Superior instruments…

Diamond synchrotron source

Superior instruments…

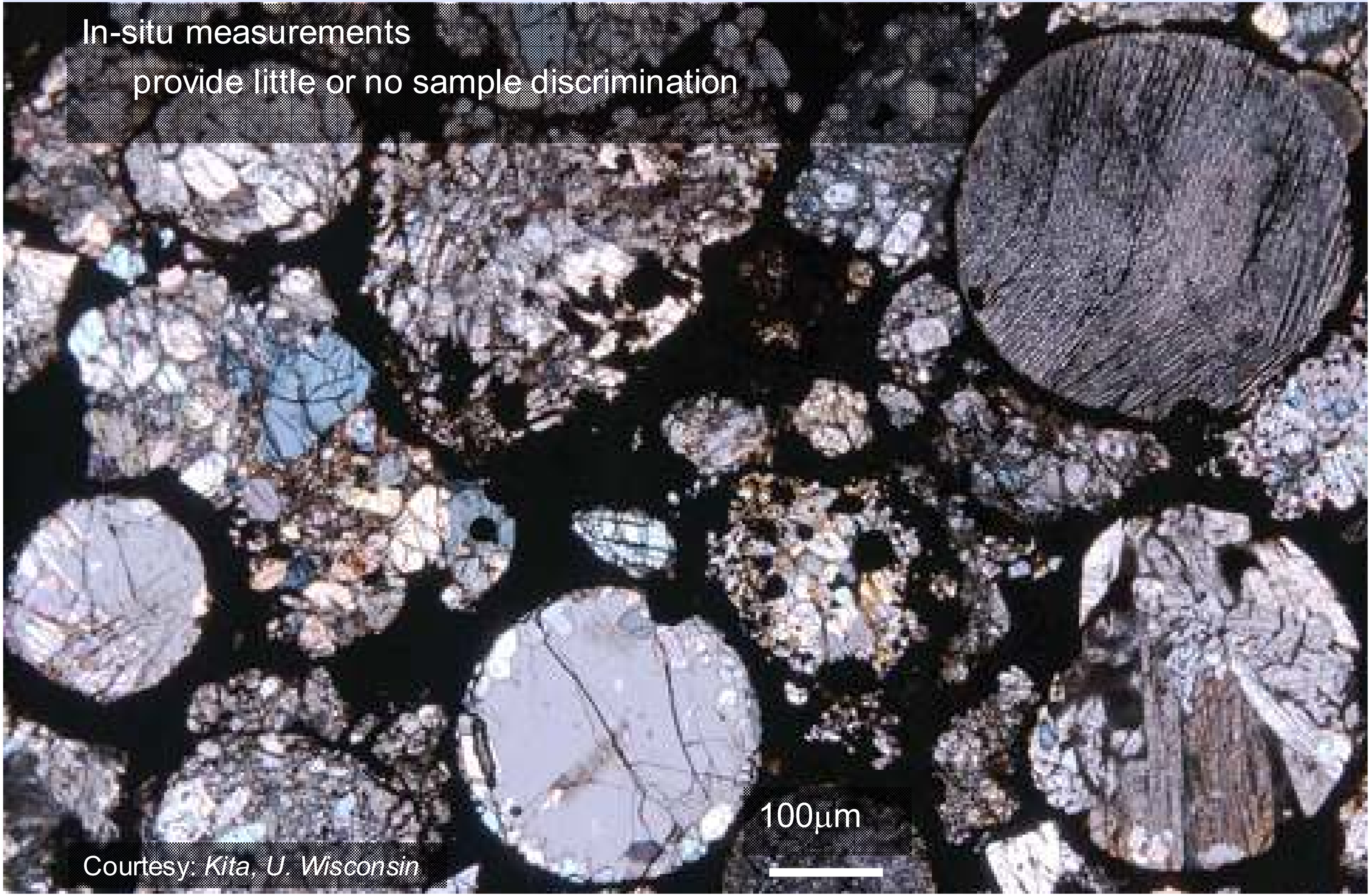
In-situ measurements provide insufficient precision

Whole-rock measurements



Grady, 2004

In-situ measurements provide little or no sample discrimination



Courtesy: *Kita, U. Wisconsin*

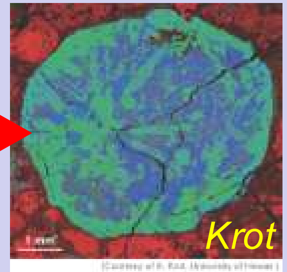
Complexity…

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

Initial selection

Split

Process characterisation

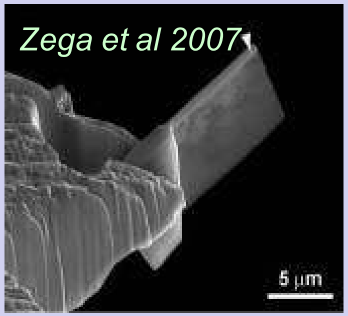


Example: isotope dating of chondritic components

Isotope dating

- Dissolution
- Purification
- Analysis
- Calibration

Context (mm–µm) – check secondary effects

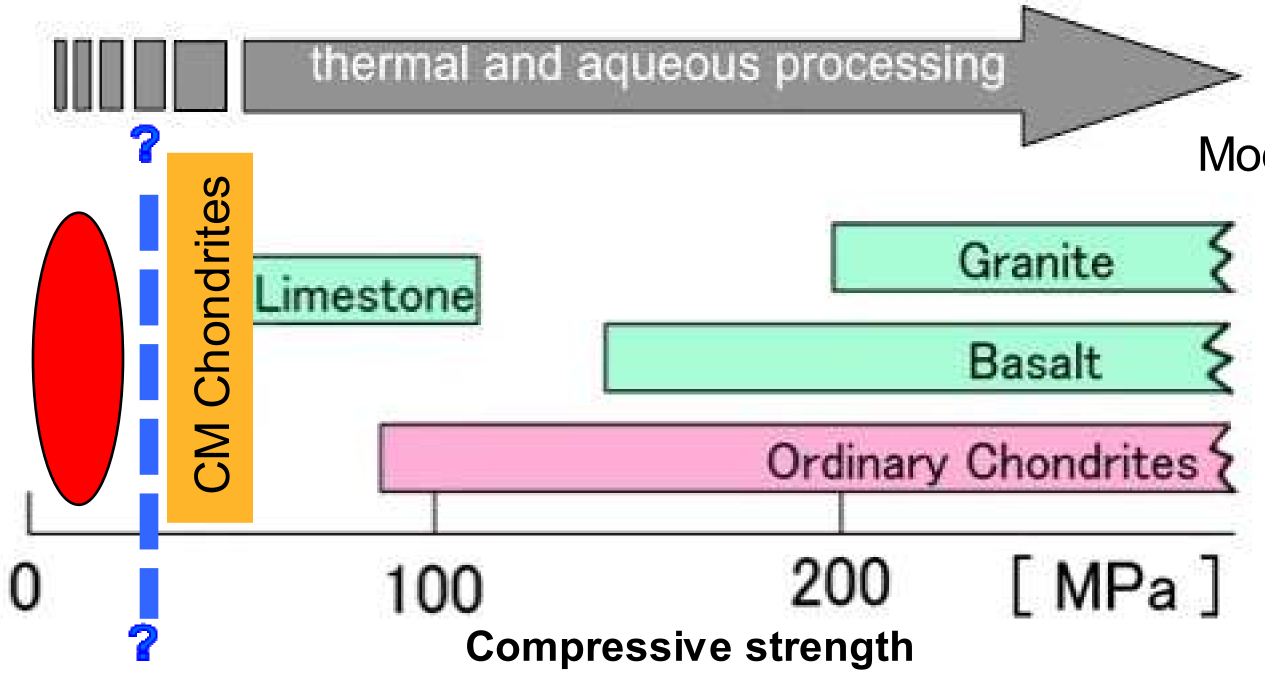


“Why do you need to return samples when we have meteorites?”

Going beyond meteorites

Re-distributes
elements
& isotopes,
Modifies
minerals
& organics

Accreted
material?

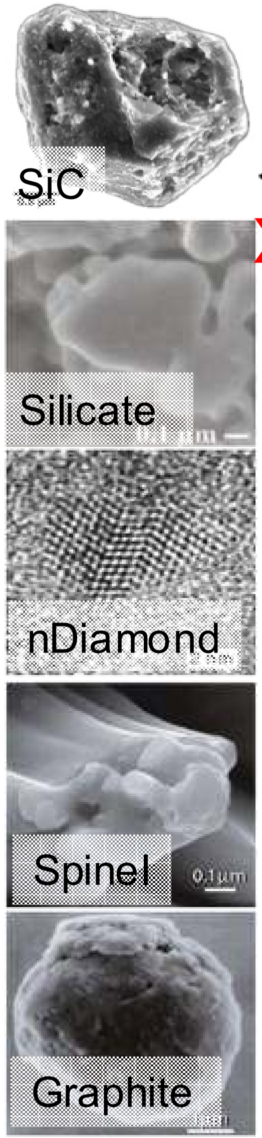


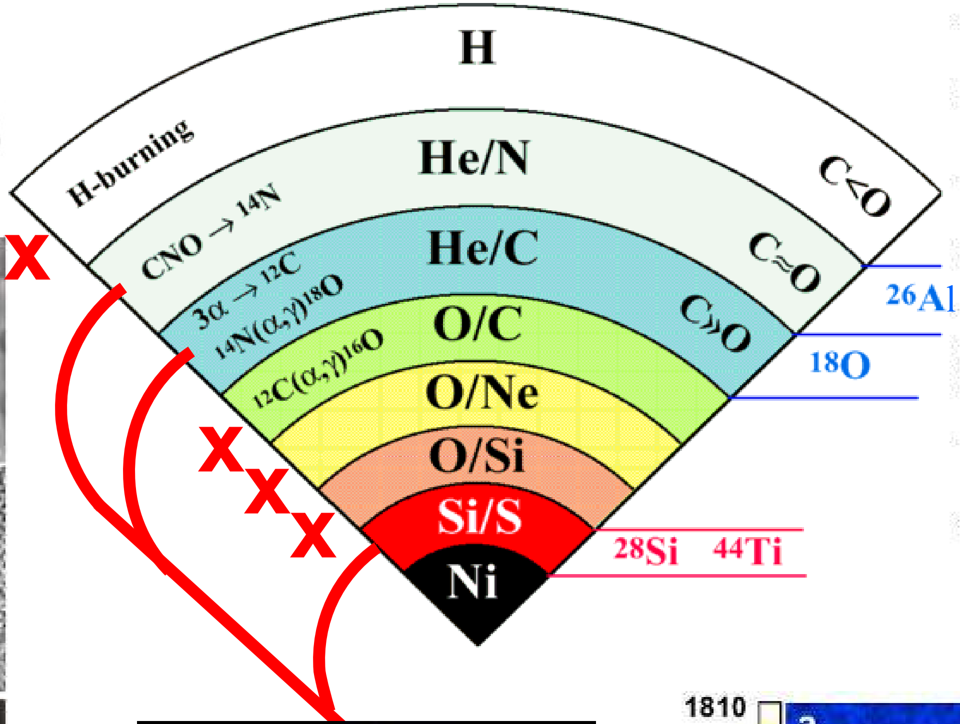
Atmospheric Entry
Filter?

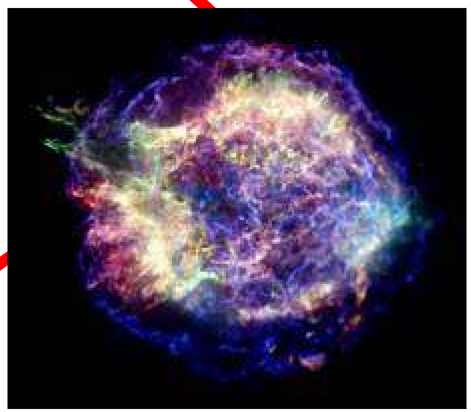
To survive atmospheric entry *requires* major processing

Pre-solar grains

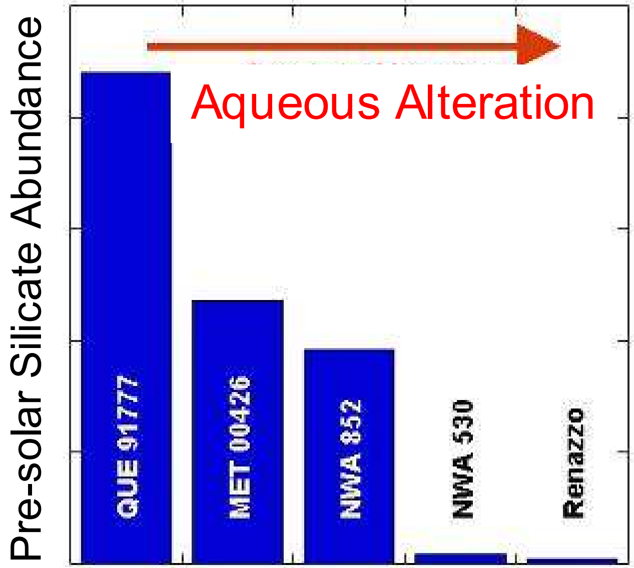
Many sources, and stellar environments

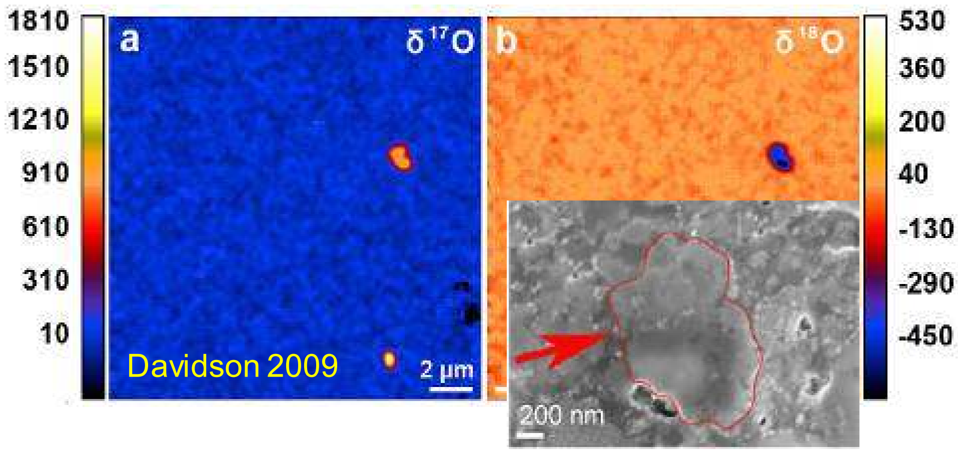






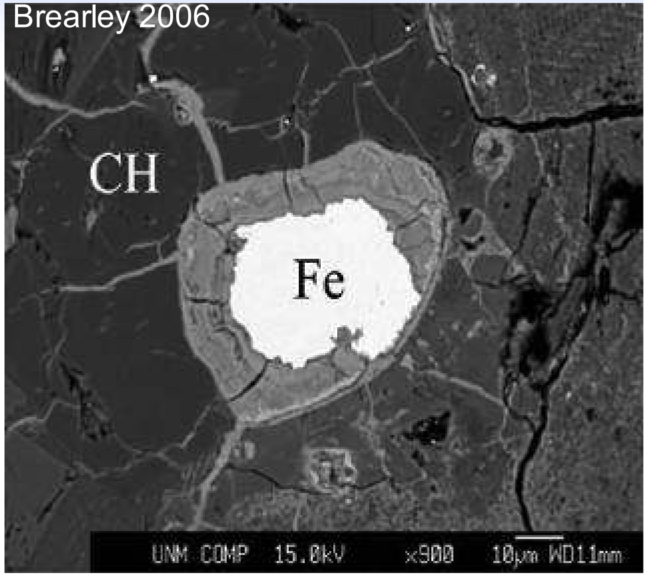
After Davidson 2009 unpublished





Aqueous alteration

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

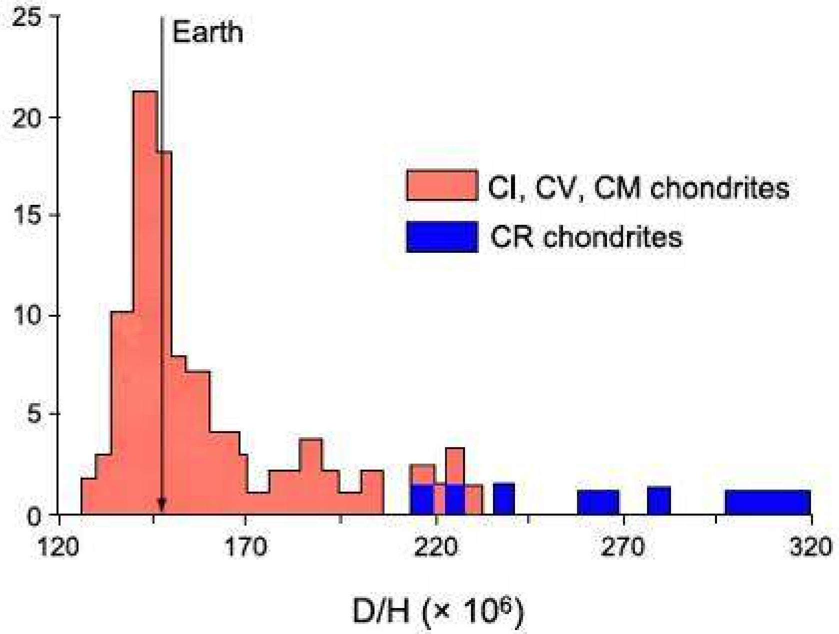


Water

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?



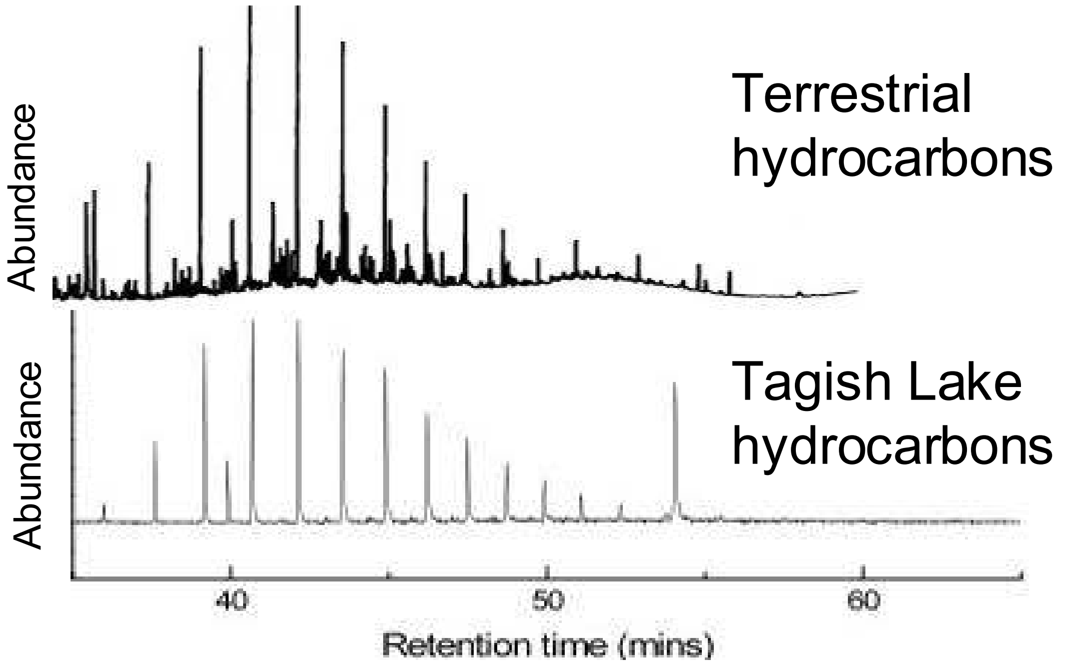
Avoid contamination…

Tagish Lake
Most perfectly collected sample?

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

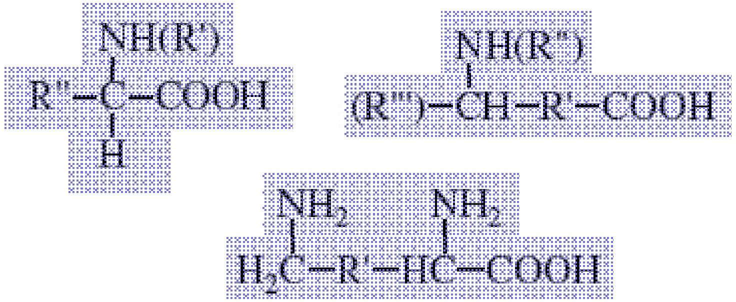
→ terrestrial contamination

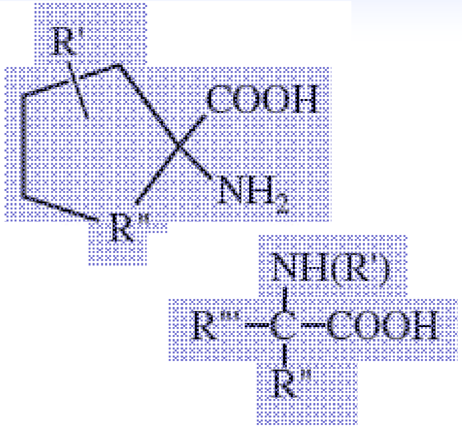
… any result obtained for organics in meteorites may be questioned

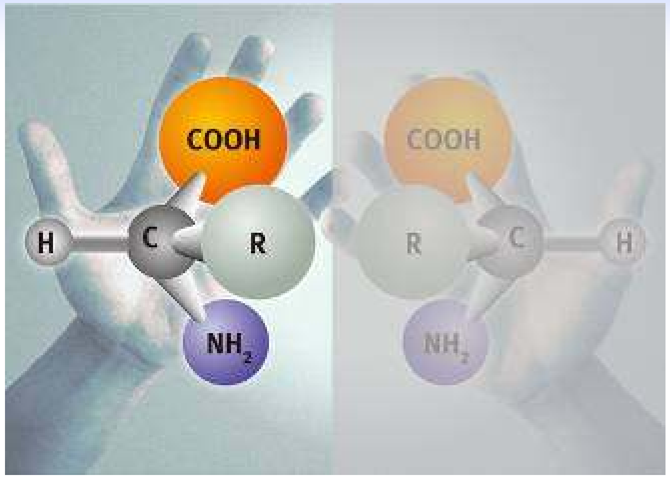


Organics

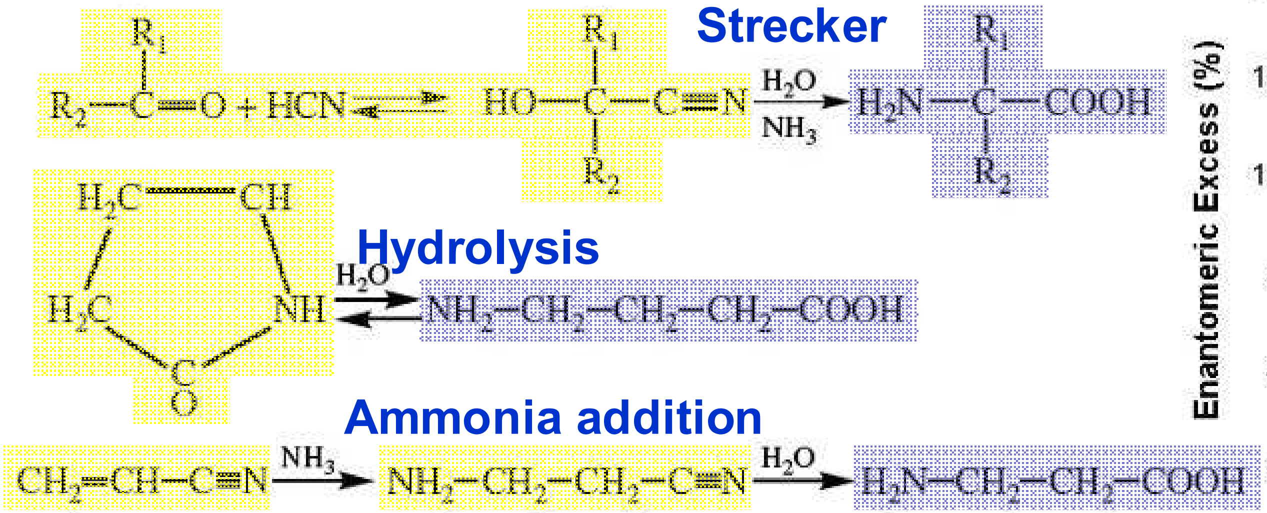
Over 80 ET amino acids

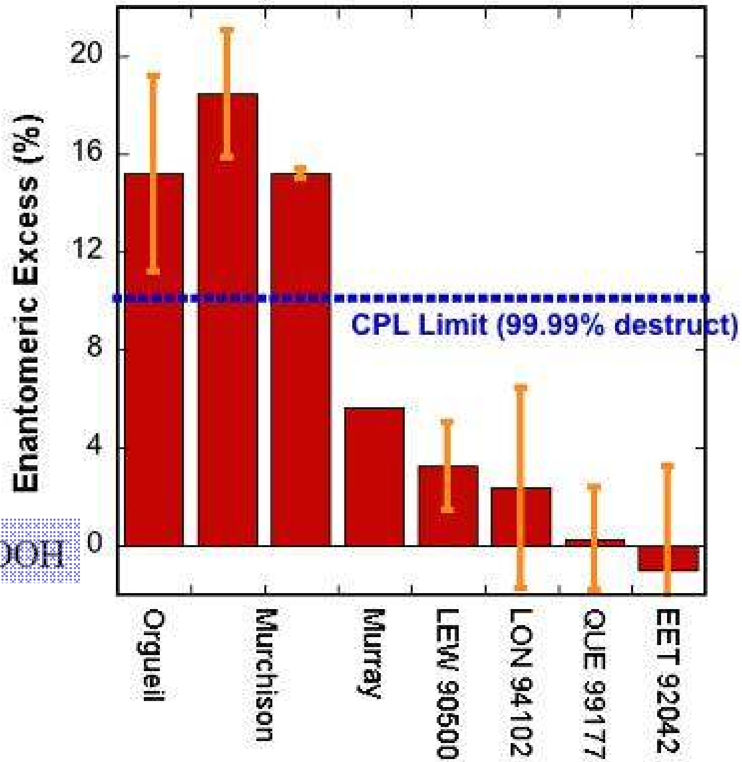






Many different synthesis mechanisms





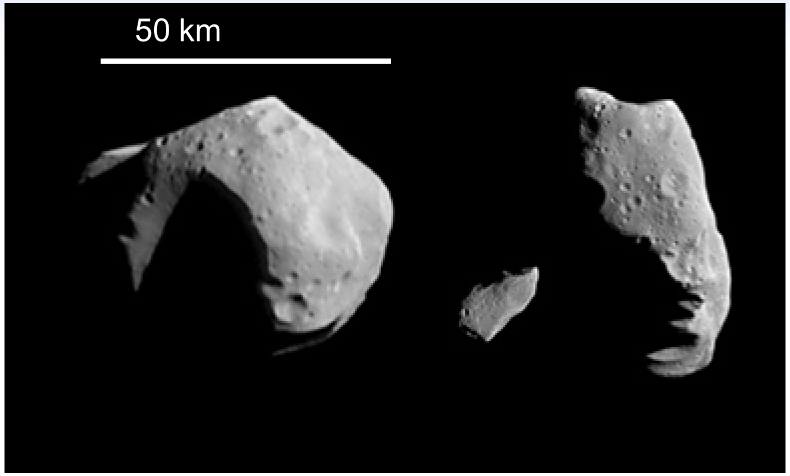
Requires precise abundances of molecules and precursors

Context

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

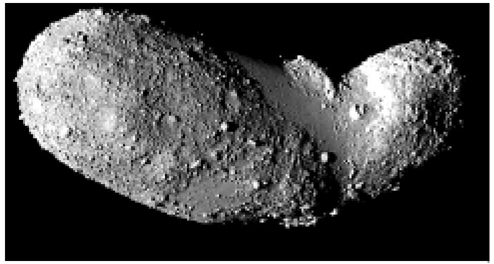
Meteorite/NEA spectra/ground truth

Laboratory data:
Petrology, composition, chronology



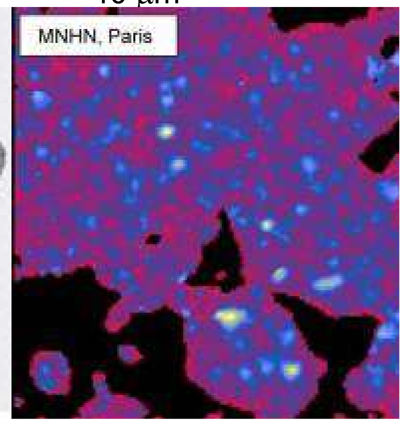
1 km

500 m



10 cm

40 µm



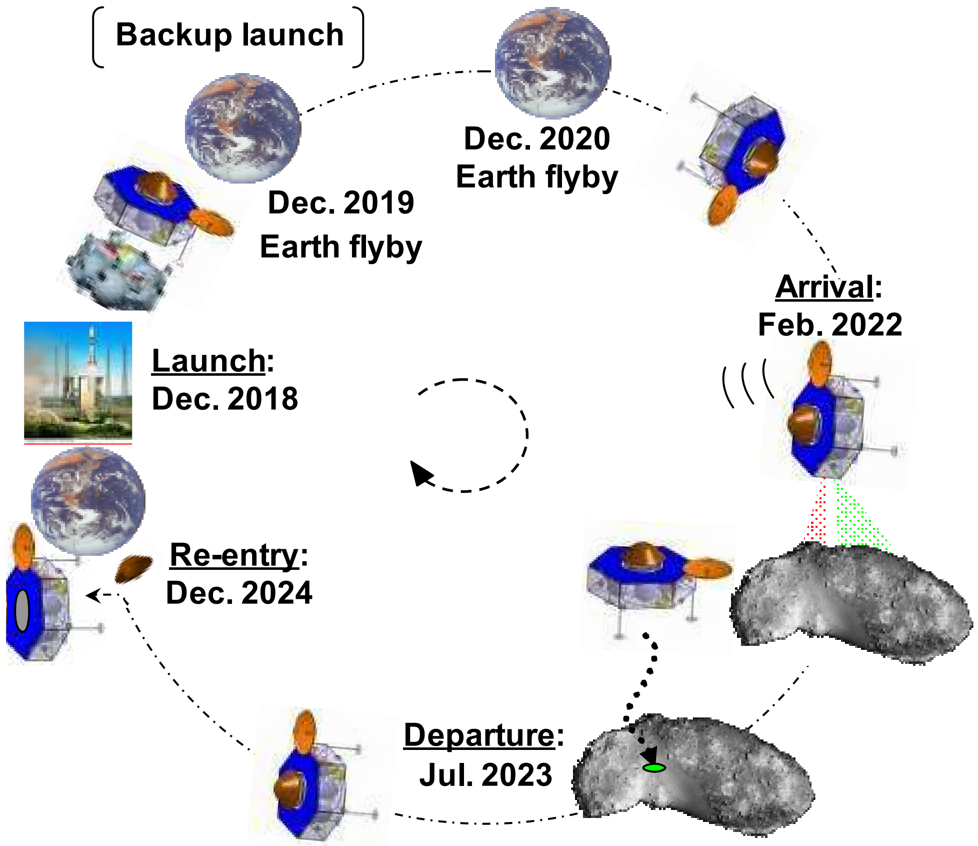
NEA sample return will use a combination of in situ and laboratory measurements to

- ✓ 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

David Hardy

Mission profile

- 6 year mission to 1999 JU_3 (17 months at the asteroid)
- Direct escape, single spacecraft (chemical) + Earth re-entry capsule
- Launch mass: ~1450 – 1560kg
- Total delta-V ~ 1600 $m \cdot s^{-1}$
- Re-entry velocity ~ 12 $km \cdot s^{-1}$
- 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)

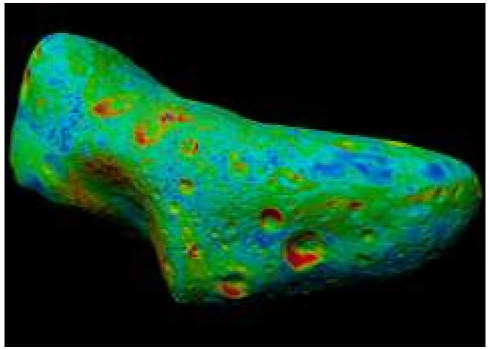
MIR spectrometer (5–25 μm)

Radio science

Laser altimeter

Neutral particle analyser

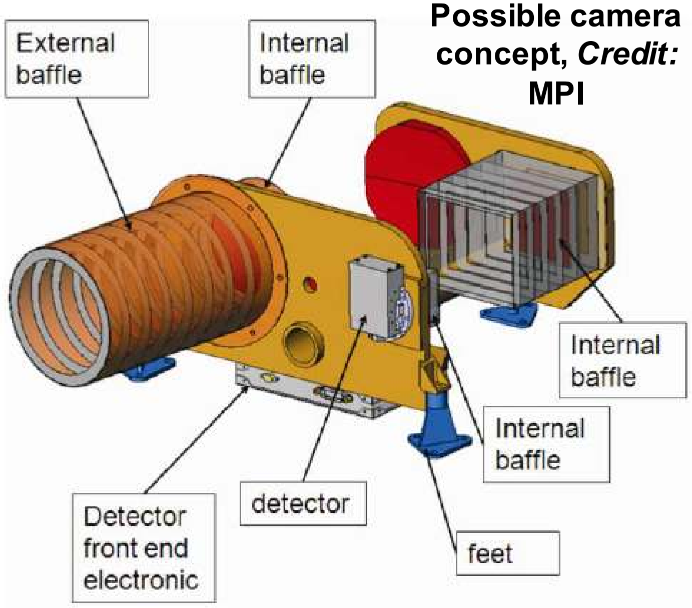
Complementary instruments/lander possible



Coloured image of Eros, *Credit:* NASA

	Total
Mass [kg]	30
Power [W]	90
Data volume [Gbit]	280

Development compatible with overall schedule



Possible camera concept, *Credit:* MPI

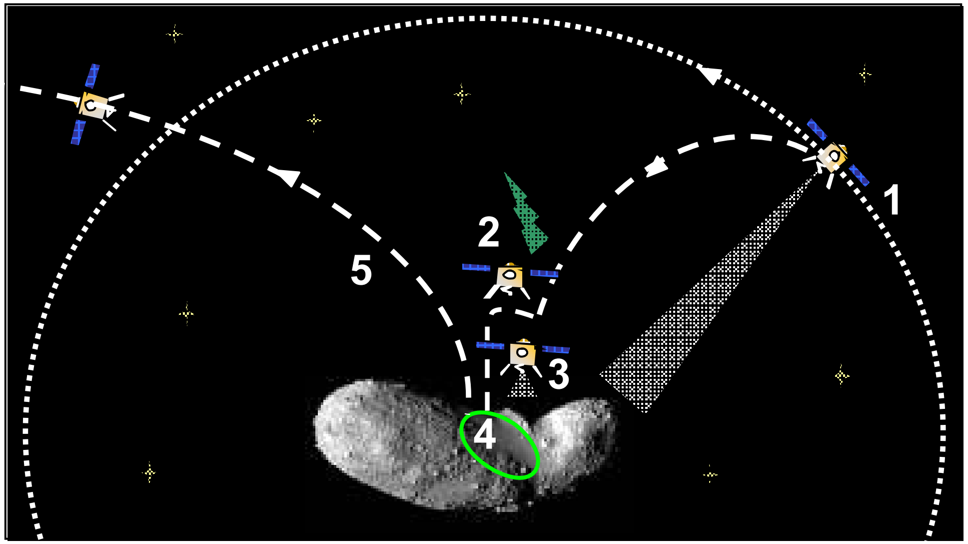
Descent/Sampling

Landing/touchdown

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

Sampling

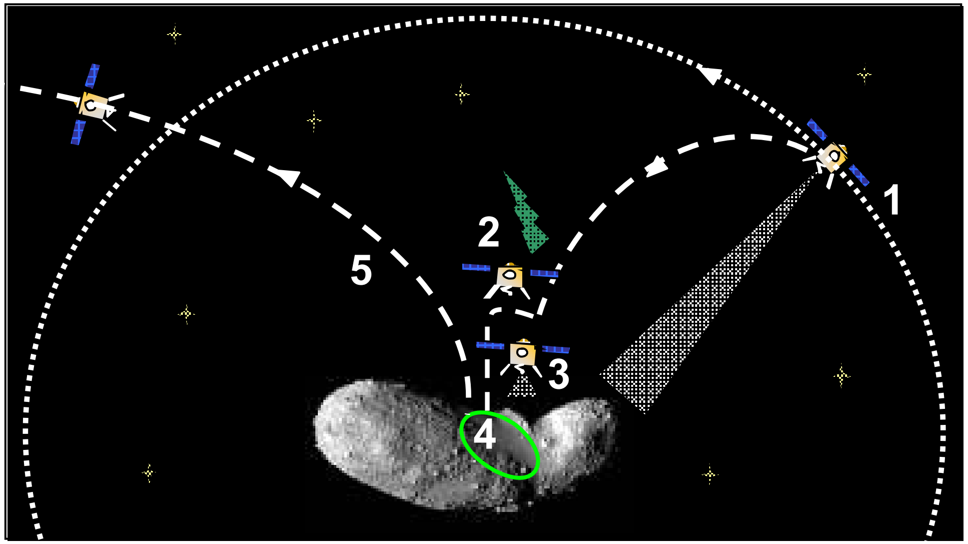
- Dust to cm-sized fragments
- Contamination-avoidance strategy



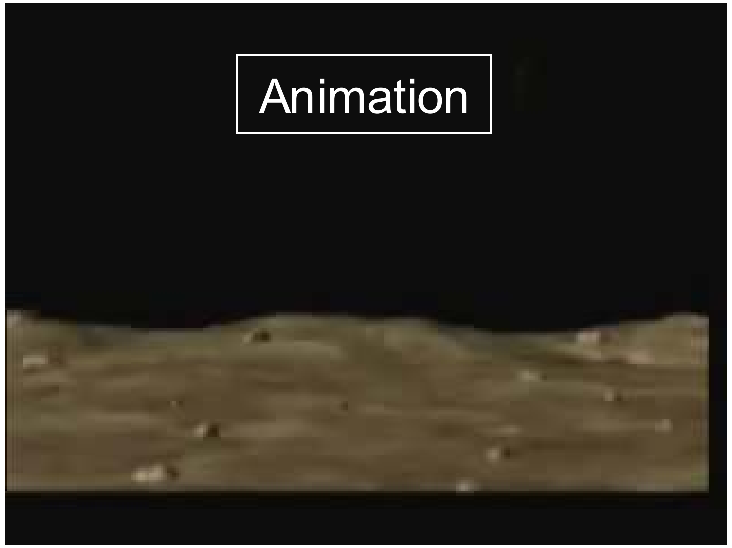
Asteroid descent and sampling sequence

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



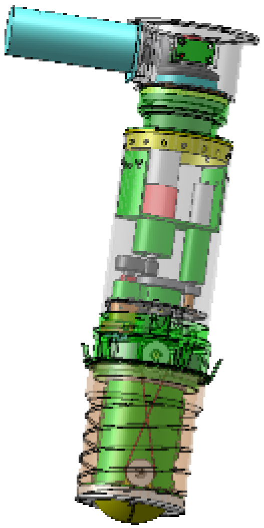
Asteroid descent and sampling sequence



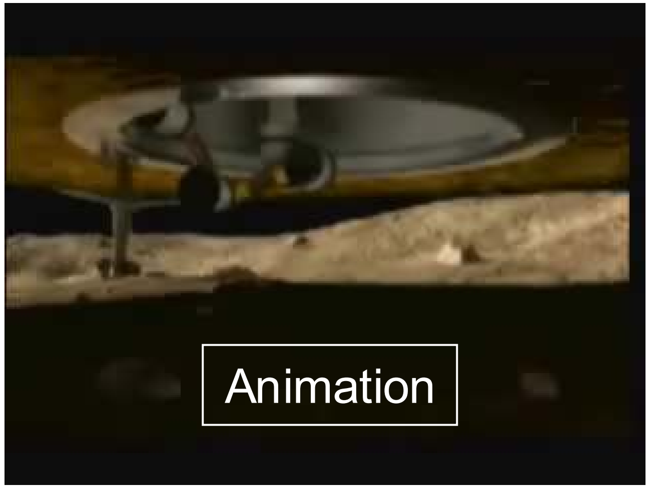
Example of touchdown operation

Descent/Sampling

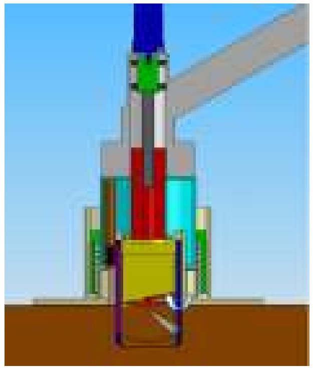
- **Sampling option 1:** Short-term landing (~ 10 min.), "energy-absorbing" landing legs, down-thrust, rotating corer (sample canister)
- **Sampling option 2:** Touch & go (< 3 sec.), "elastic" legs, fast sampler (sample canister)



Rotating corer designs



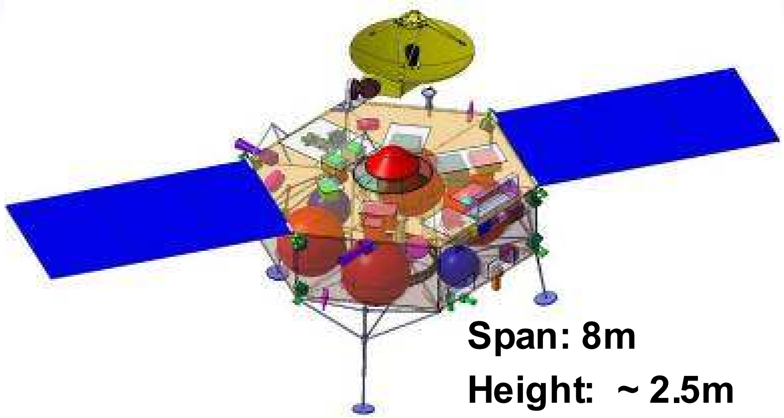
Example of sampling operation

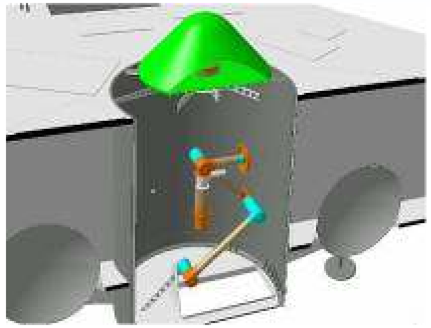


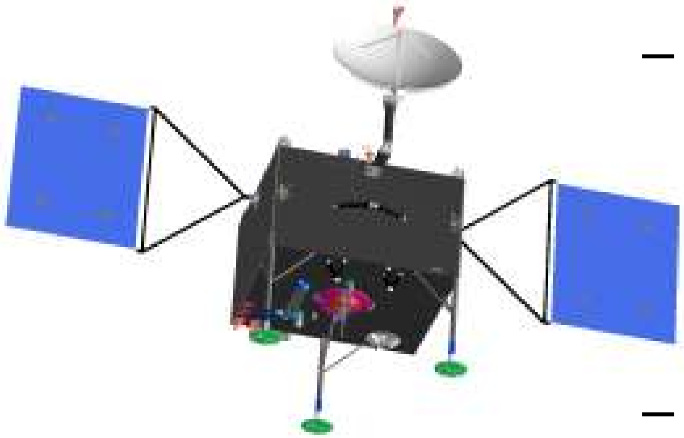
Fast sampler

Main spacecraft

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

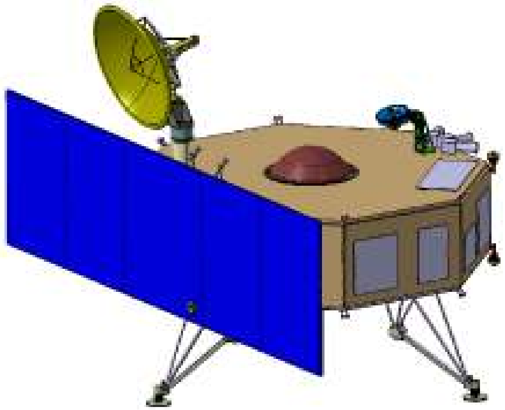


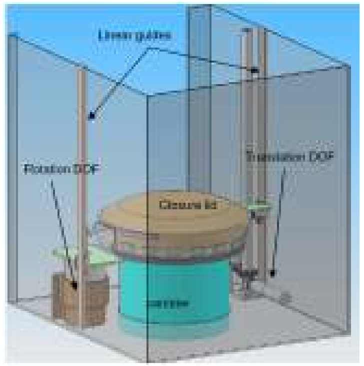




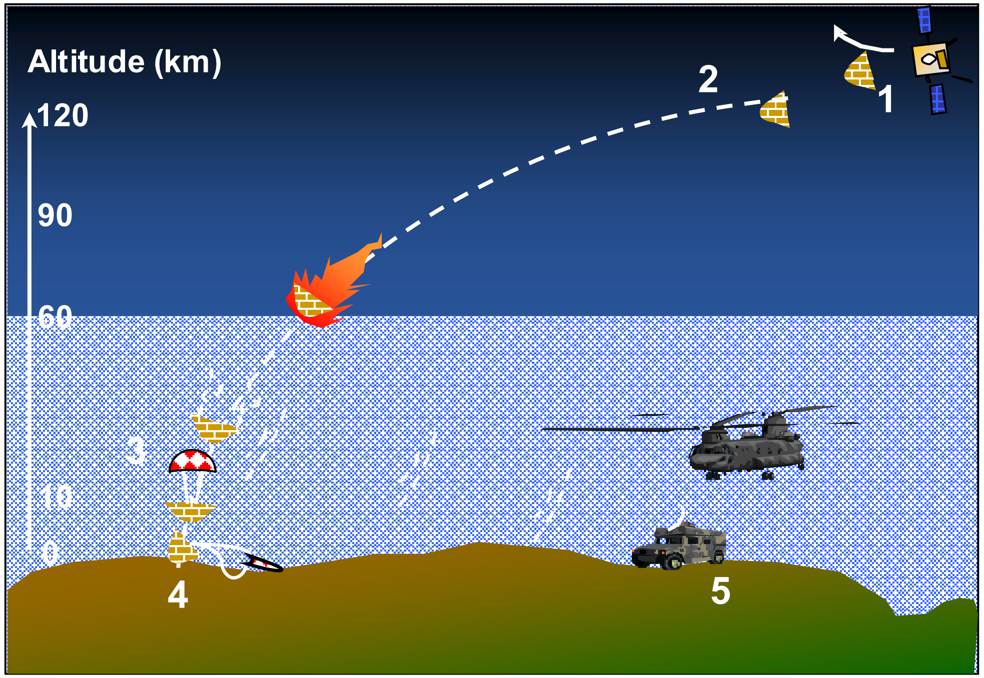
Concept 2: Corer,
bottom-mounted capsule,
two articulated arms

Concept 3: Fast sampler,
top-mounted capsule,
transfer via landing pads/legs
+ elevator in central cone





Earth re-entry

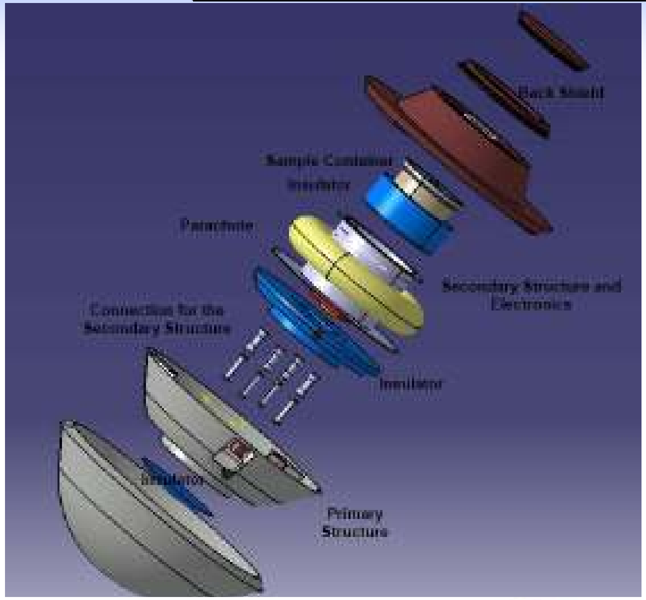


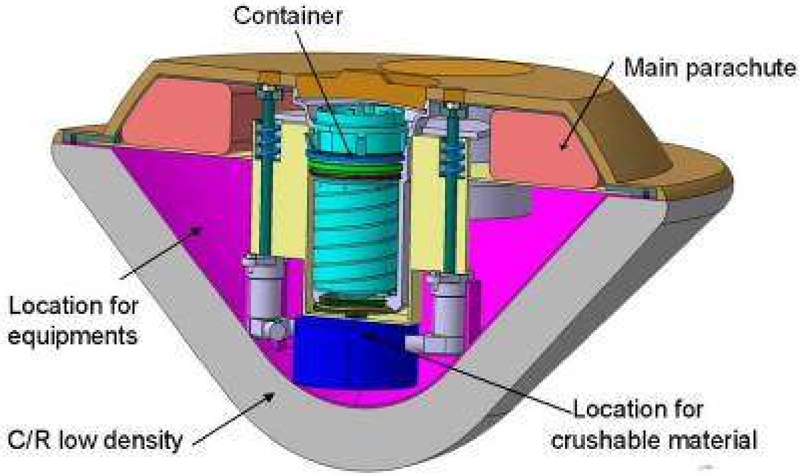
Stardust capsule recovery operations, *Credit:* NASA

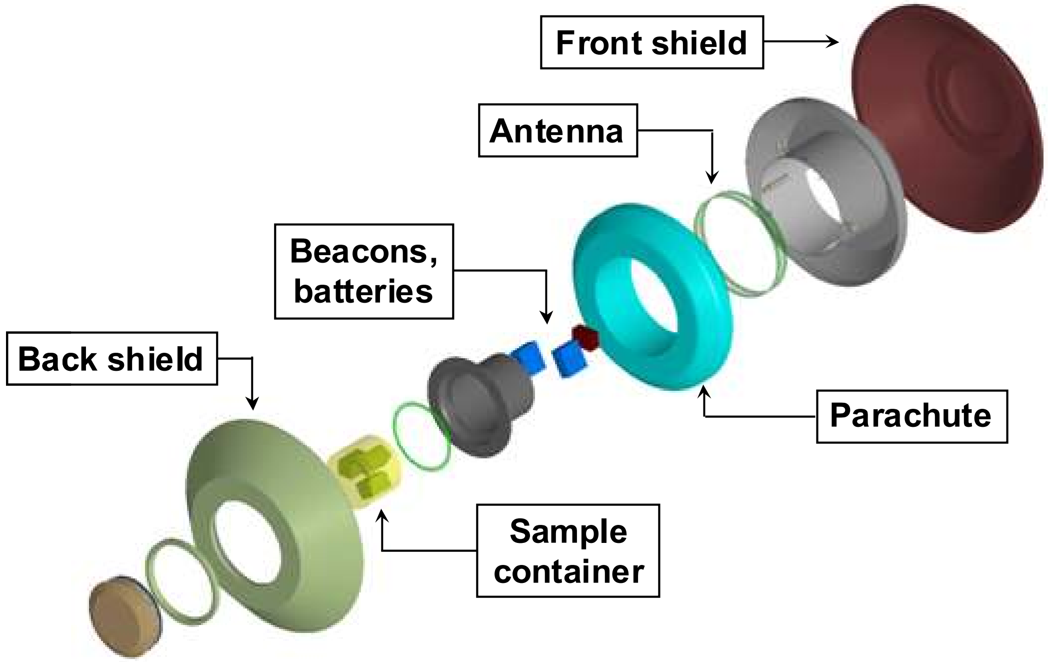
1. T_0 – 4 hours: Separation with main spacecraft
2. T_0: Re-entry (heat flux ~ 15 MW·m^{-2})
3. T_0 + 200 s: Parachute opening (~ 10 km, subsonic)
4. T_0 + 1800 s: Soft landing in Woomera, Australia
5. Landing + few min/hrs: Search & Recovery

Earth re-entry capsule

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



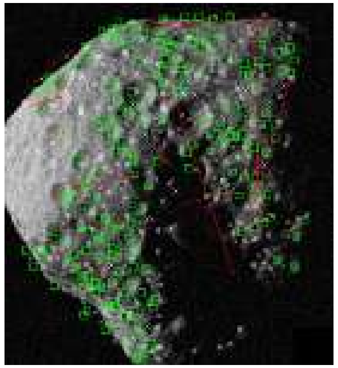




Development

- **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**

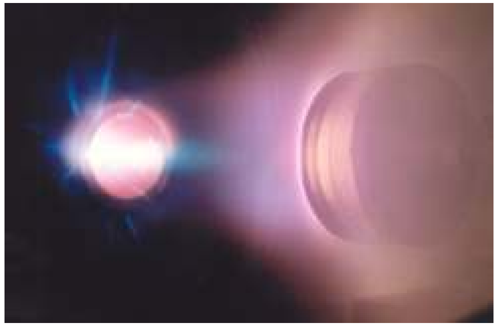
Navigation camera
Astrium



Navigation landmarks
TAS

Sampling test results
SENER

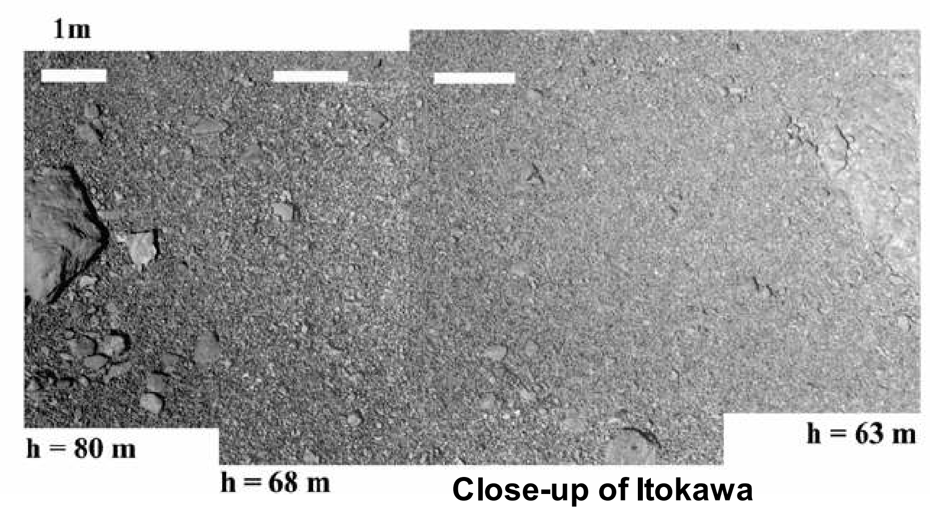
Sampling test results
SELEX Galileo



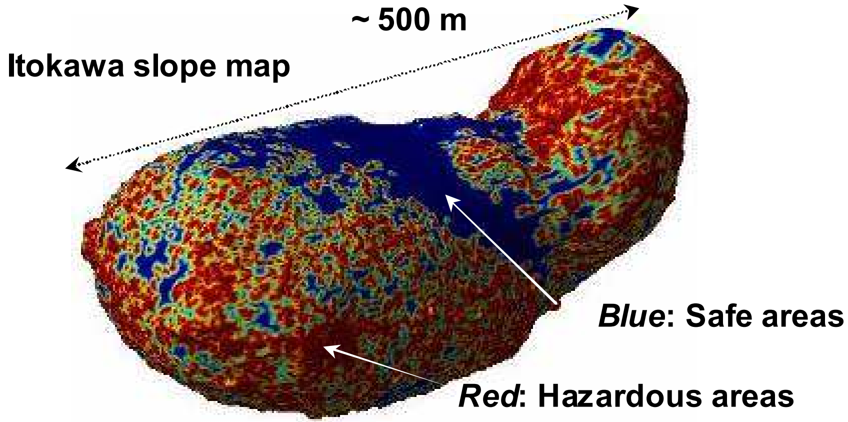
High heat flux test of heat shield material, *IRS*

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



Close-up of Itokawa surface, *Credit:* JAXA



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

Conclusions

✓ **Technically feasible mission**

	Contractor 1	Contractor 2	Contractor 3
Total dry mass	745	744	812
Launch mass	1448	1462	1557
Launch vehicle performance	1629	1719	1629
Launch mass margins (%)	11	15	4

Marco Polo spacecraft mass budget (kg)

✓ **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)