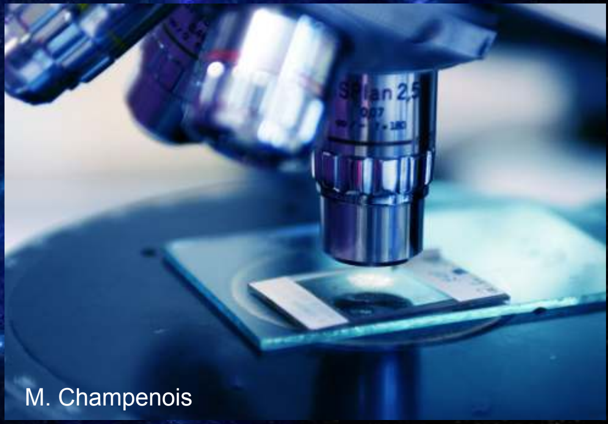
Near Earth Asteroid Sample Return

MarcoPolo-R



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On behalf of the
MarcoPolo-R Science Team

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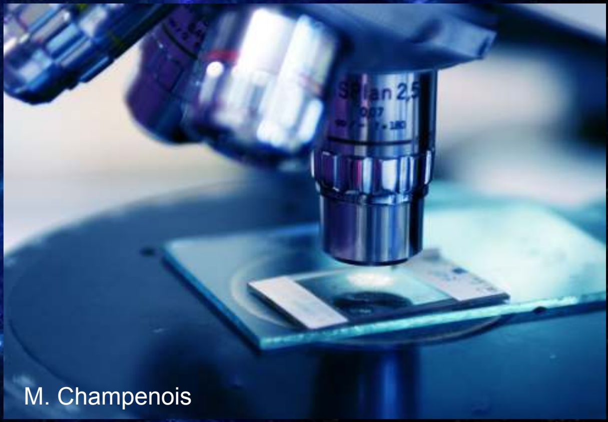
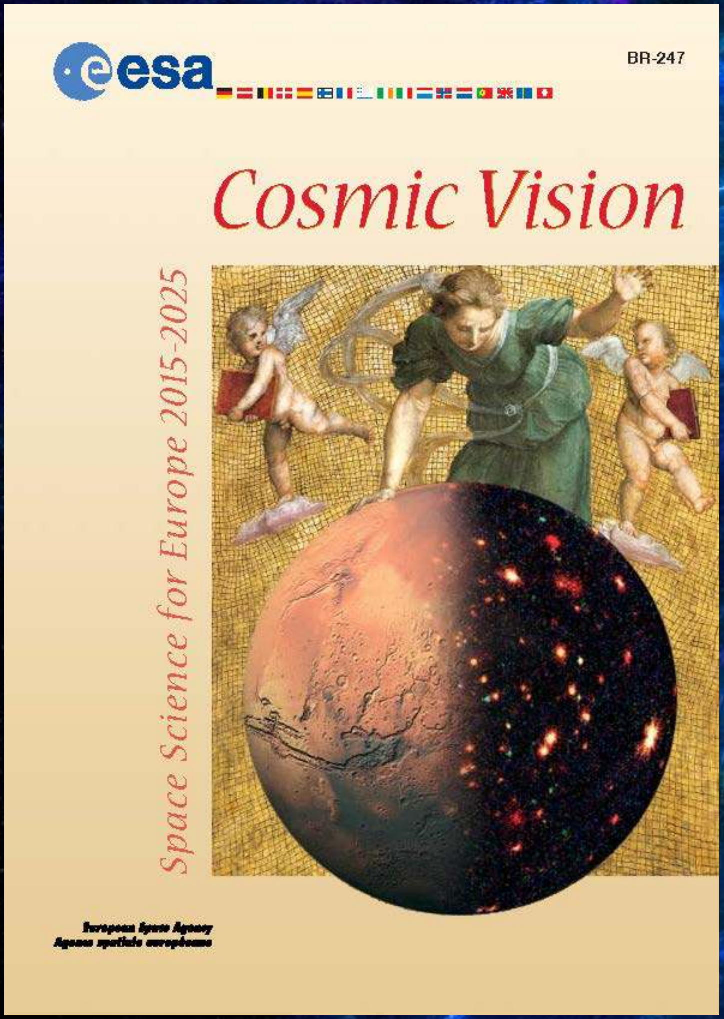


Cosmic Vision 2015-2025



MarcoPolo-R addresses the scientific questions:

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

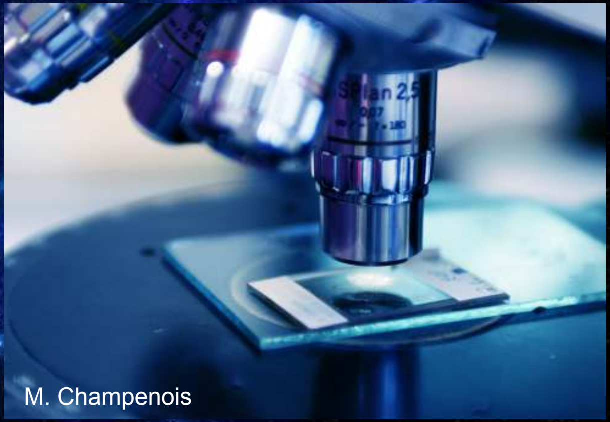
2) How does the Solar System work?

Related issue with a Near-Earth Asteroid characterization:

- Impact hazard and mitigation

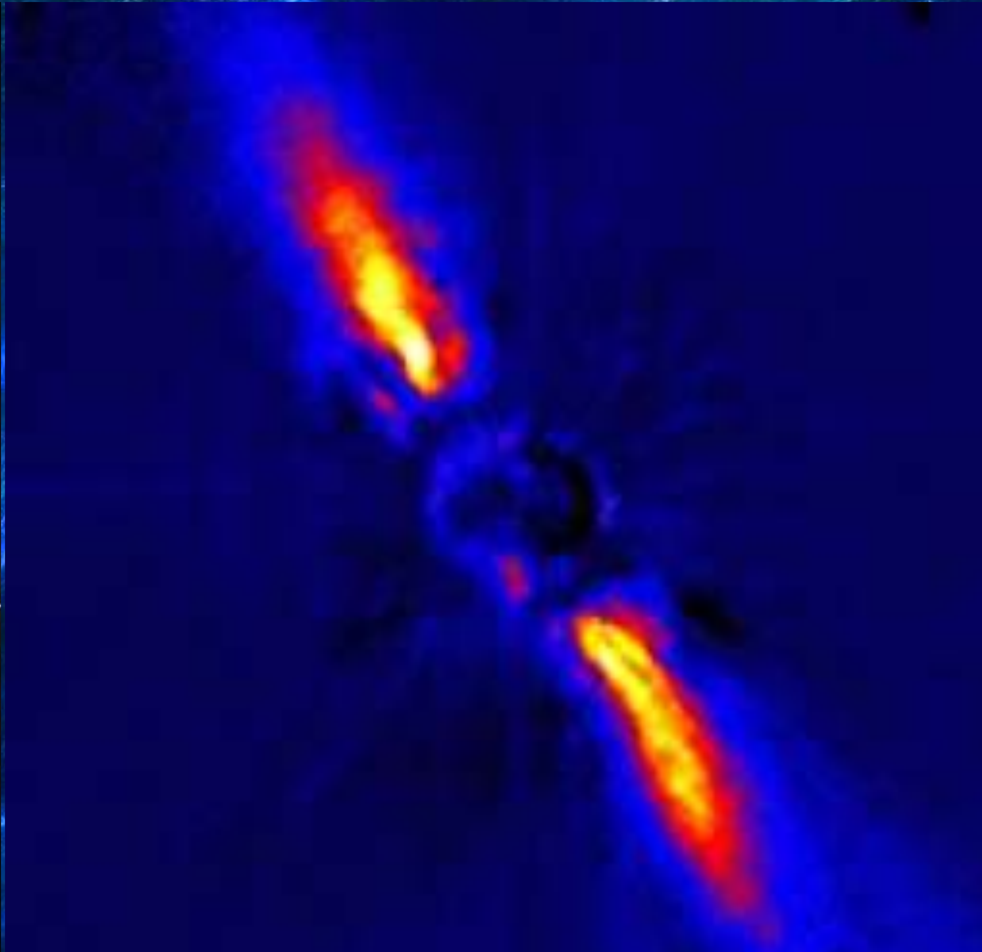
MarcoPolo-R will:

- Return ~100g of sample for high precision lab analysis
- Characterize a primitive Near-Earth Asteroid at multiple scales



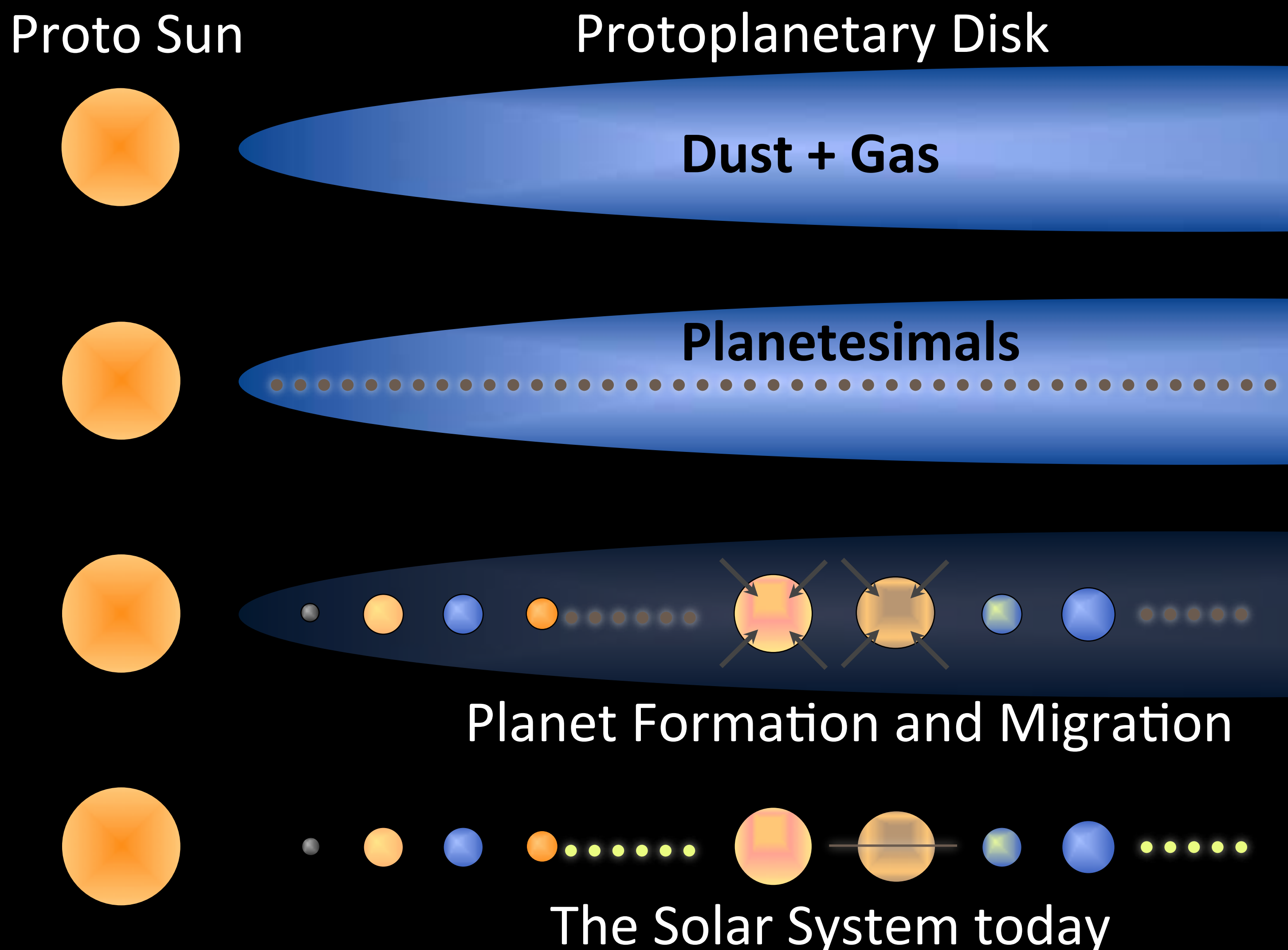
Formation & Evolution of the Solar System

Hubble Space Telescope Orion Treasury Project Team



Beta Pictoris, European Southern Observatory

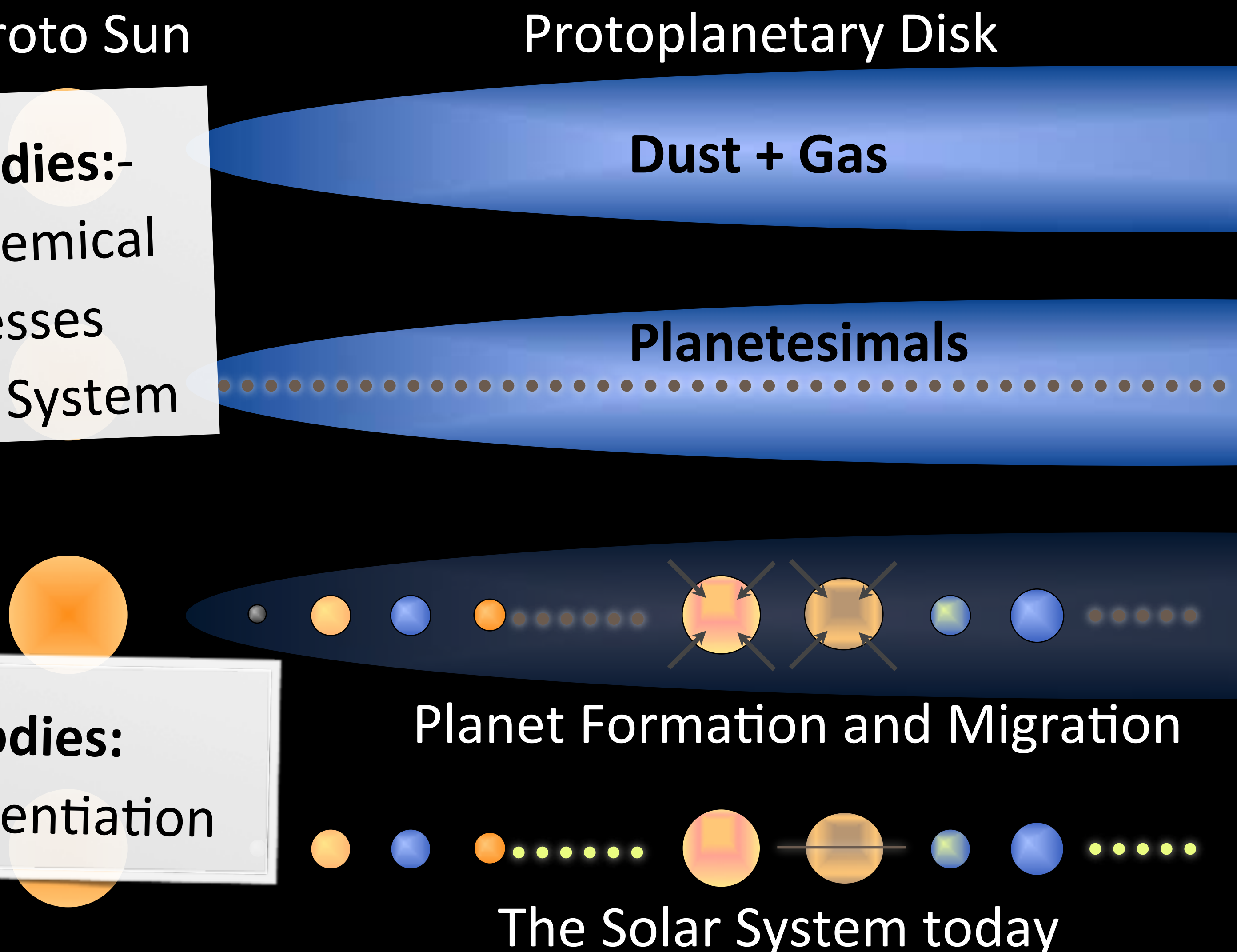
Formation & Evolution of the Solar System



Courtesy : S. Tachibana

Formation & Evolution of the Solar System

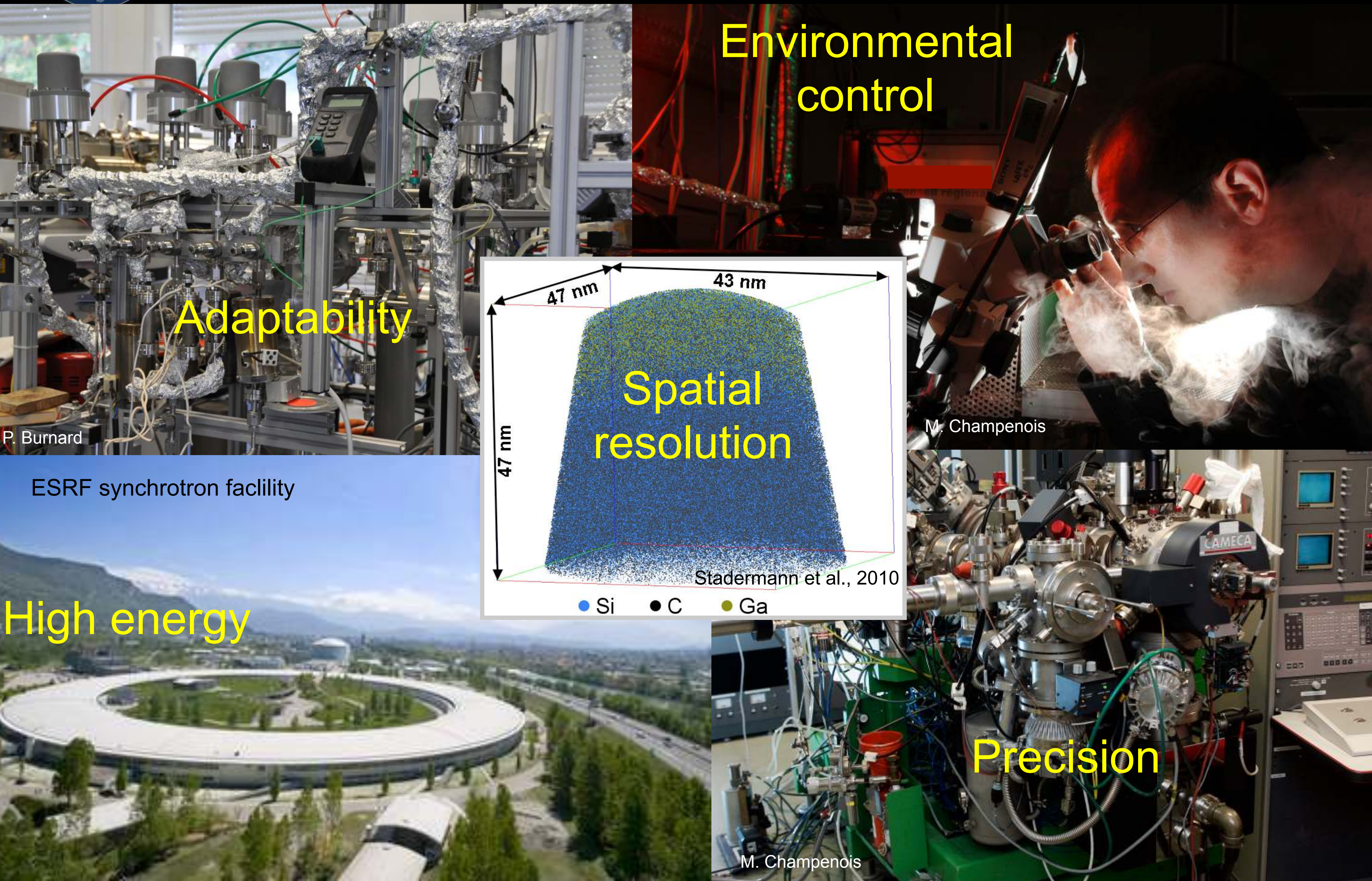
Small primitive bodies:-
record complex chemical
and physical processes
in the early Solar System



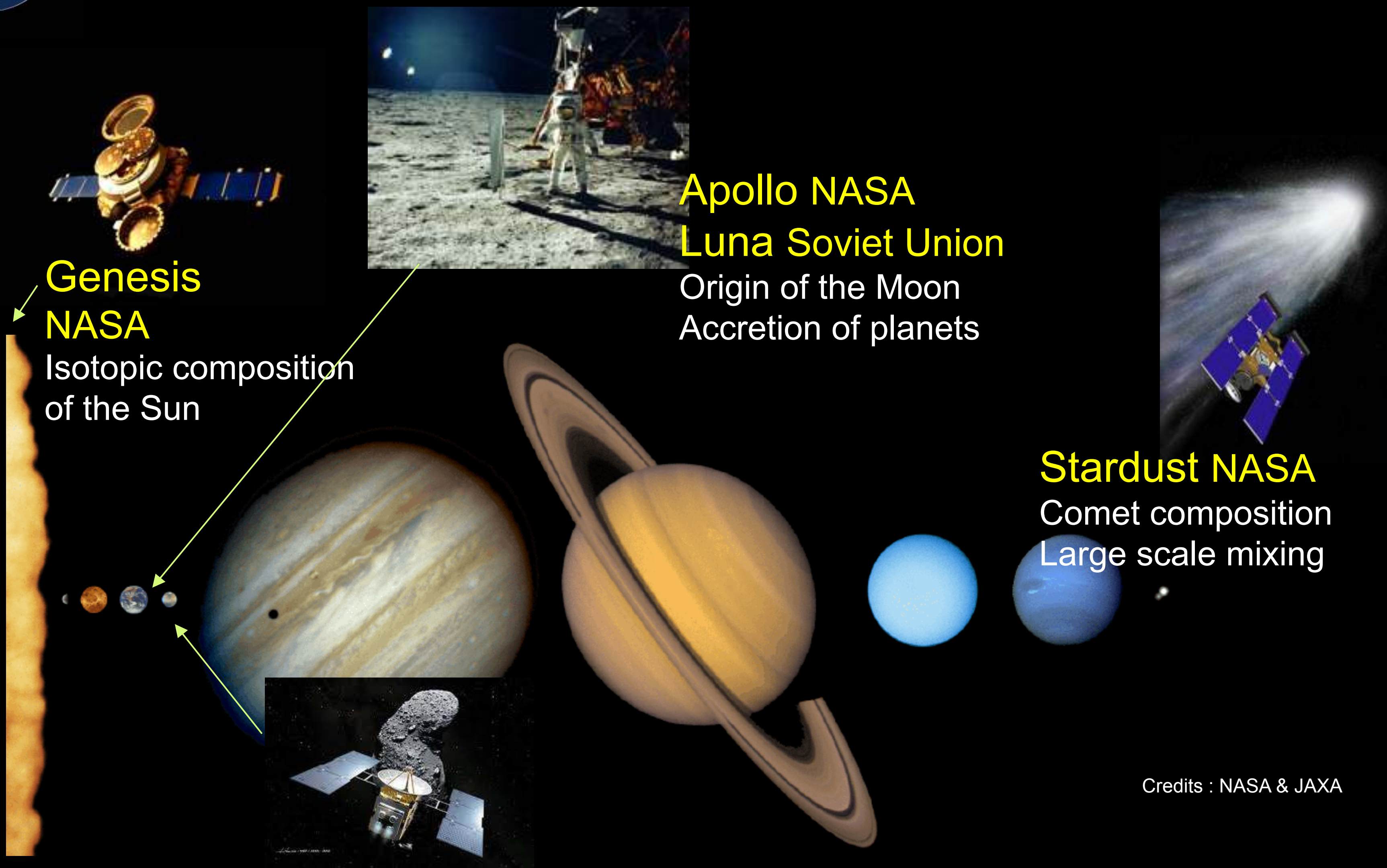
Large evolved bodies:
- melting & differentiation

Courtesy : S. Tachibana

Why sample return?



Sample return legacy



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

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

Ensisheim meteorite fall,Shedel, 1493

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.

CAMECA
SCIENCE & METROLOGY SOLUTIONS

nu instruments

ThermoFisher
SCIENTIFIC

The next two decades : exploration of asteroids

Hayabusa2
JAXA

OSIRIS-REx
NASA

MarcoPolo-R
ESA

- 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

Grand questions on the origin and evolution of the Solar System

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 ?

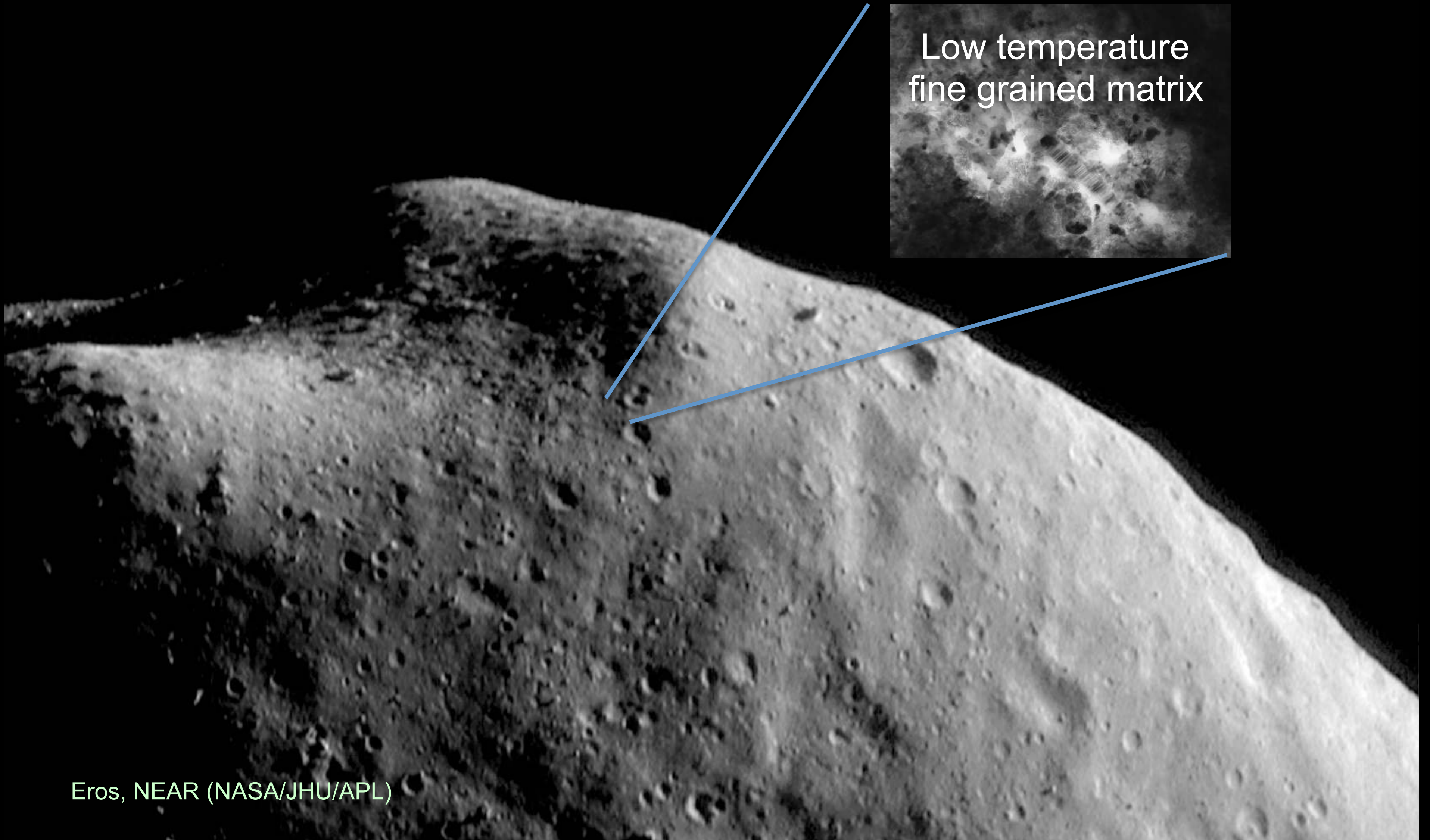
3. What are the physical properties and evolution of the building blocks of terrestrial planets ?

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 ?

Eros, NEAR (NASA/JHU/APL)

Fine–grained matrix hosting organics, volatiles



Eros, NEAR (NASA/JHU/APL)

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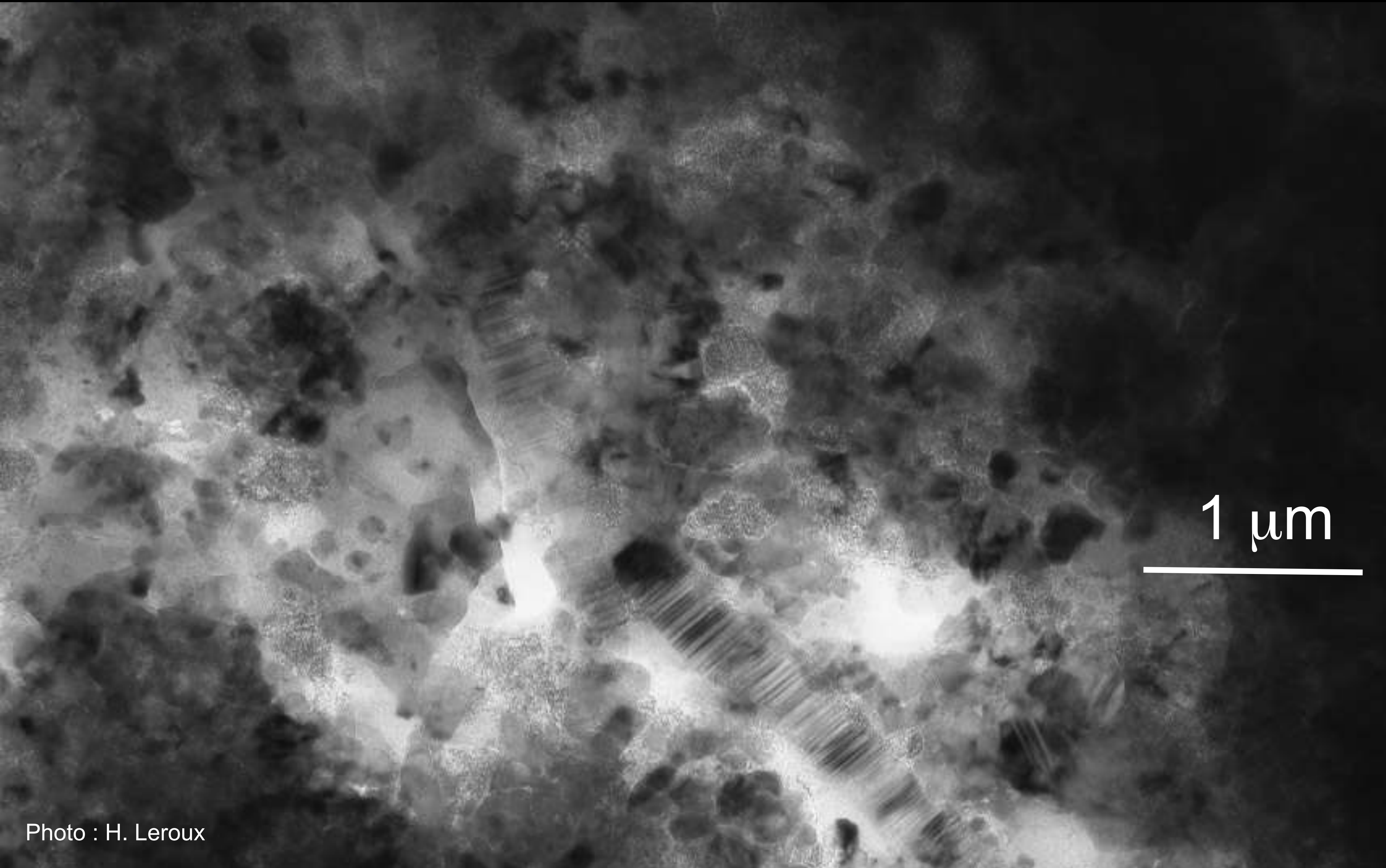
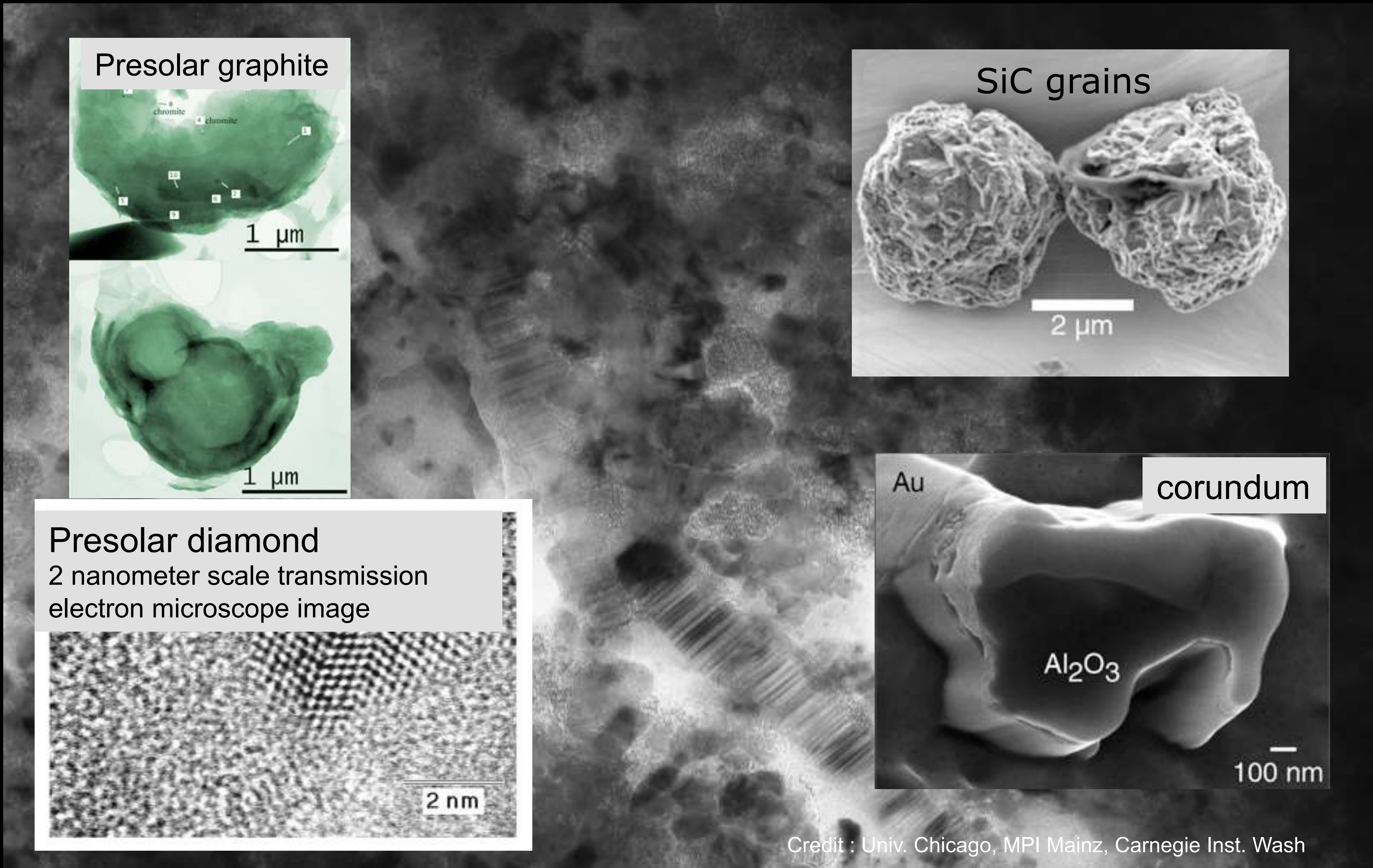


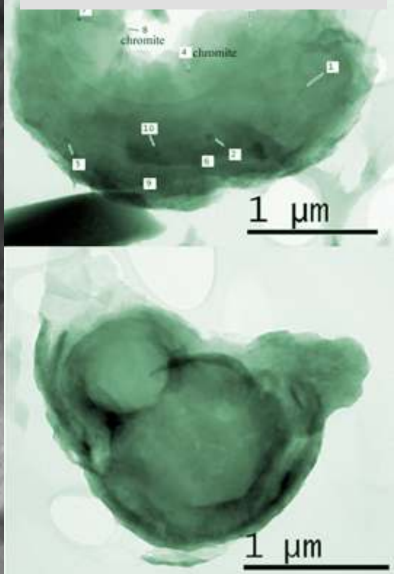
Photo : H. Leroux

Fine–grained matrix host grains of non-solar composition



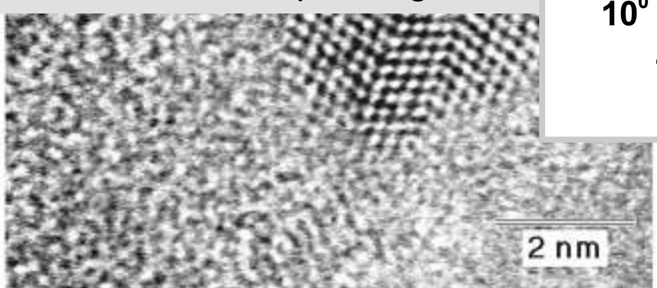
Pre-solar grains that survived Solar System formation

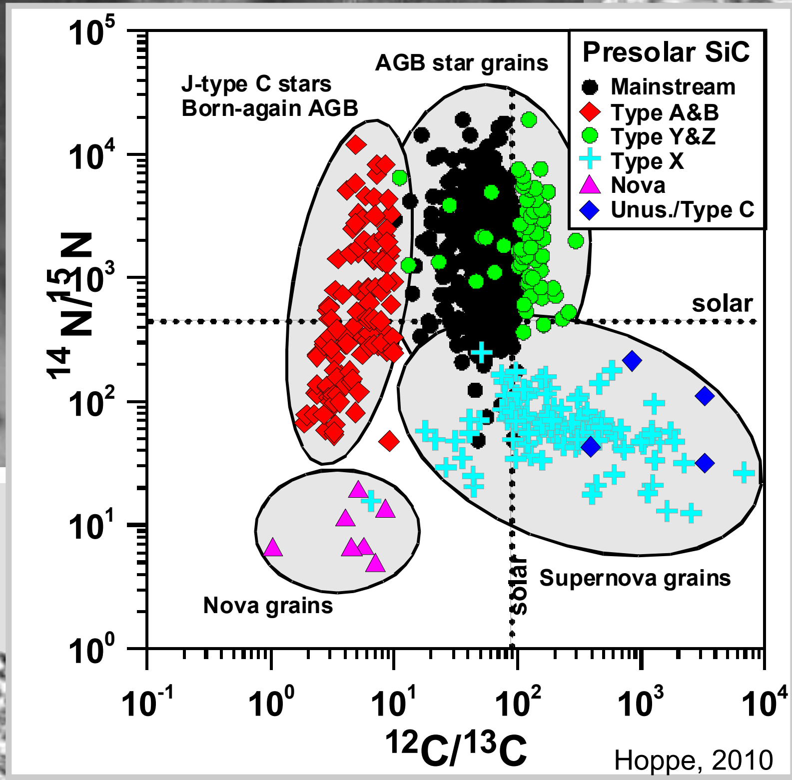
Presolar graphite



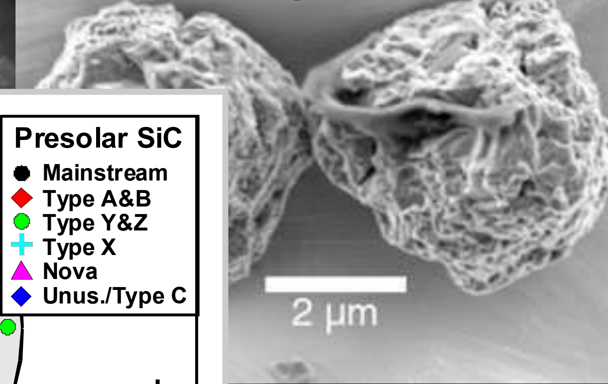
Presolar diamond

2 nanometer scale transmission electron microscope image

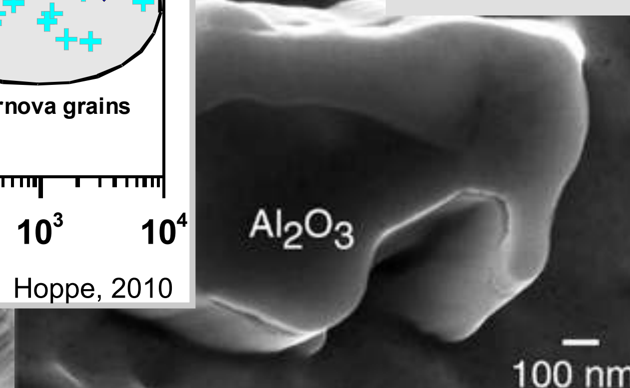




SiC grains



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 super-novae explosions (eg, ^{44}Ca)

- Insight into galactic evolution (eg AGB stars)

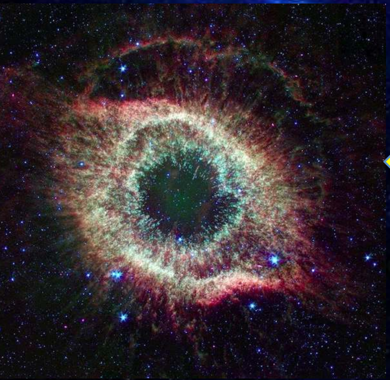
- Physico-chemical conditions and events in stellar envelopes (eg red giants)

What are the links between past stars and the Solar System ?

Supernova

Molecular Cloud

Proto-planetary disk



AGB Star

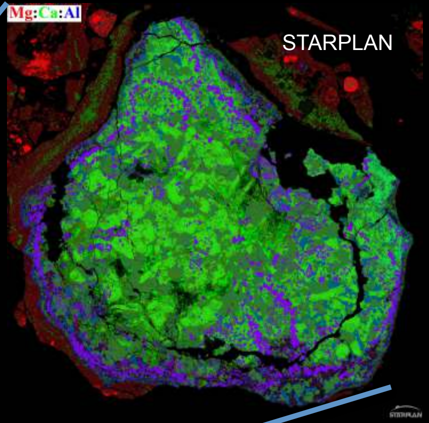
Primitive asteroids

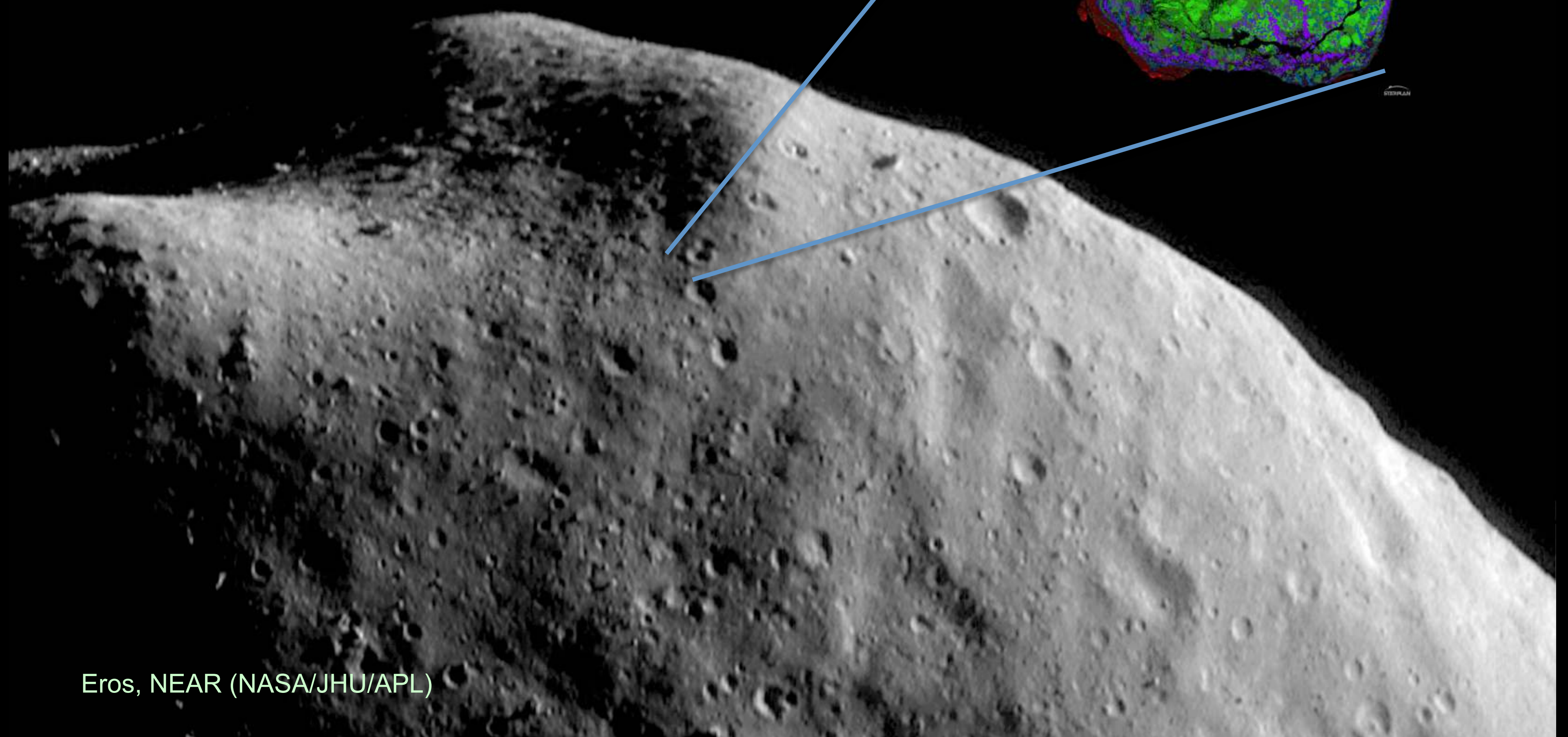
NASA, NEAR

Lab analysis

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

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



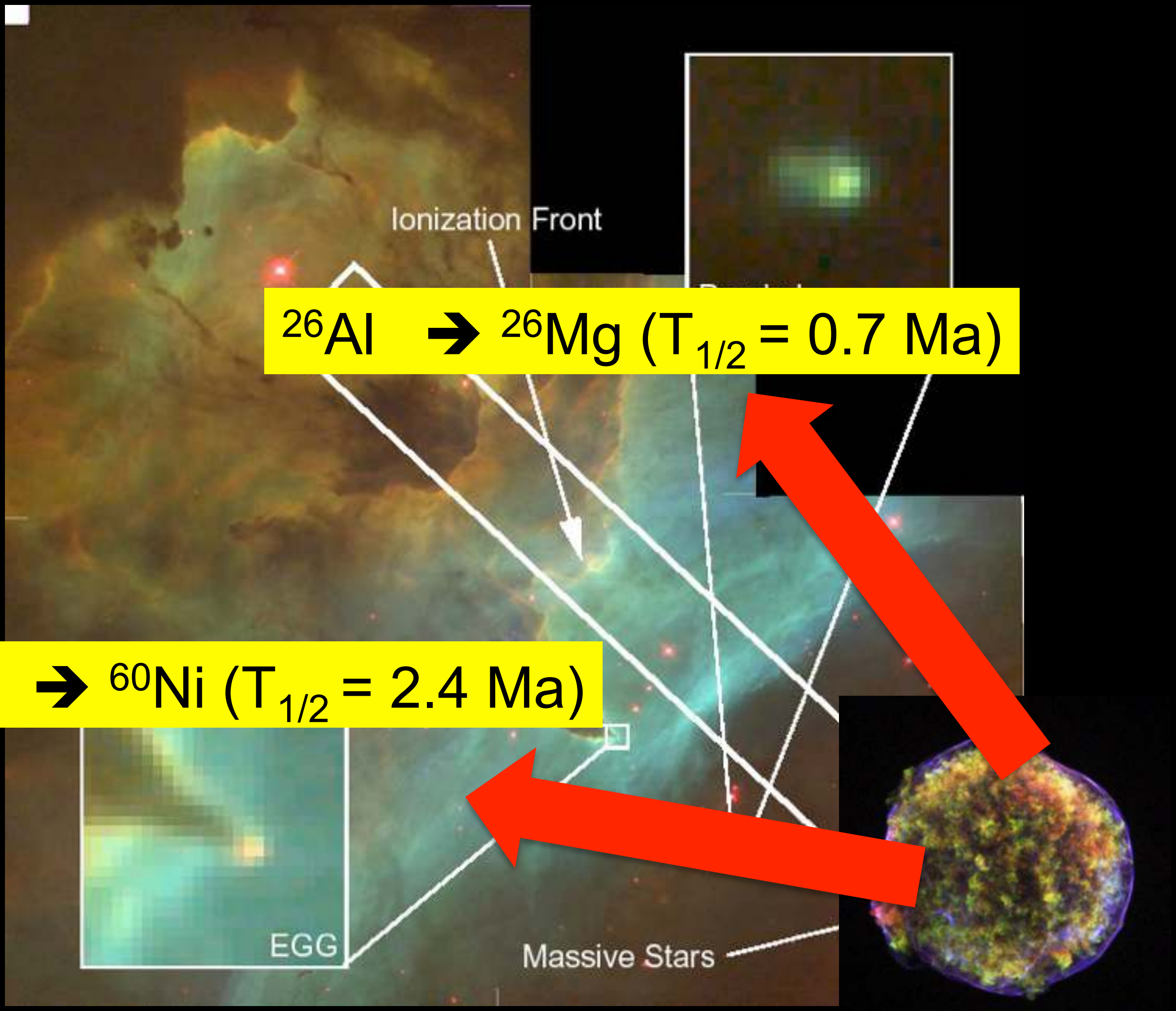


Eros, NEAR (NASA/JHU/APL)

Extinct radioactivities : key tracers of early Solar System events

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

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

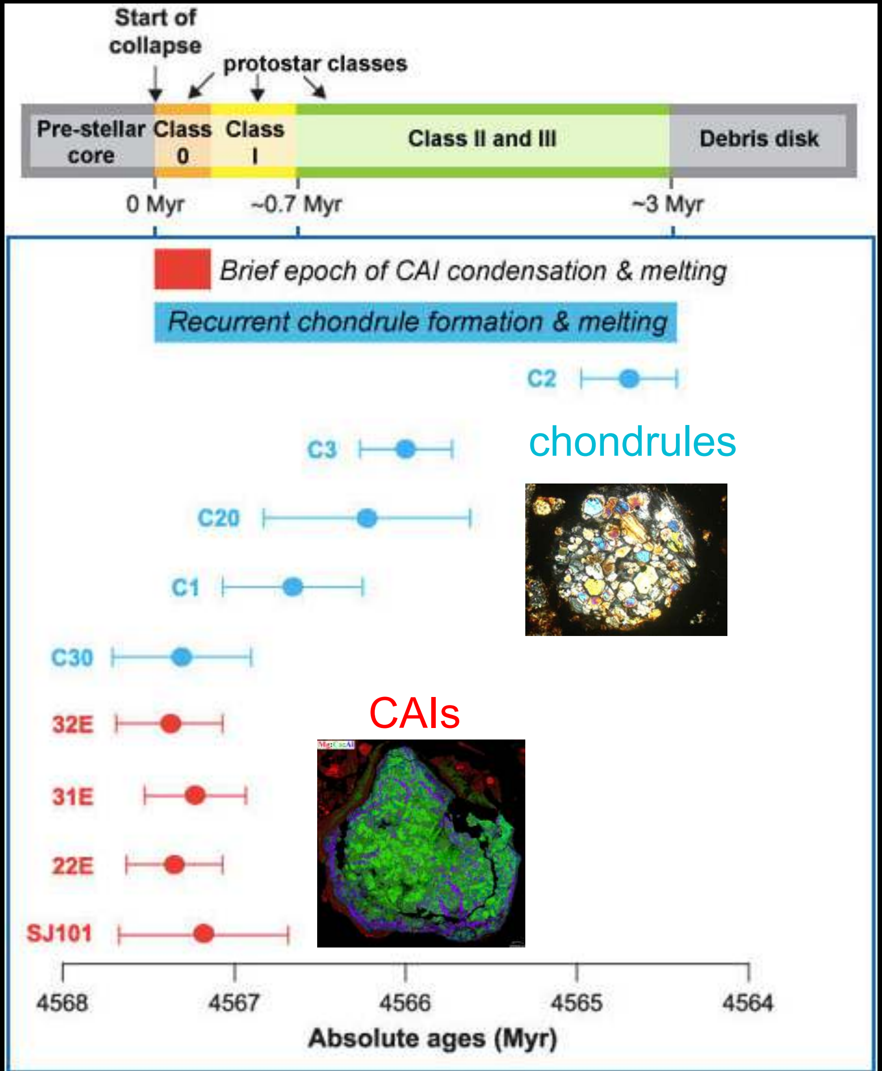


NGC 6357, Hester & Desch (2005)

Extinct radioactivities : key tracers of proto-solar events

Timing of Supernova explosions?

Time scales of nebular vs. planetary processes



(From Connelly *et al.*, 2012, *Science*, v. 338, p.651-655, doi: 10.1126/science.1226919.)

- Radioisotope systems are susceptible to resetting during meteorite forming process
- Samples of primitive unaltered material should significantly improve chronology

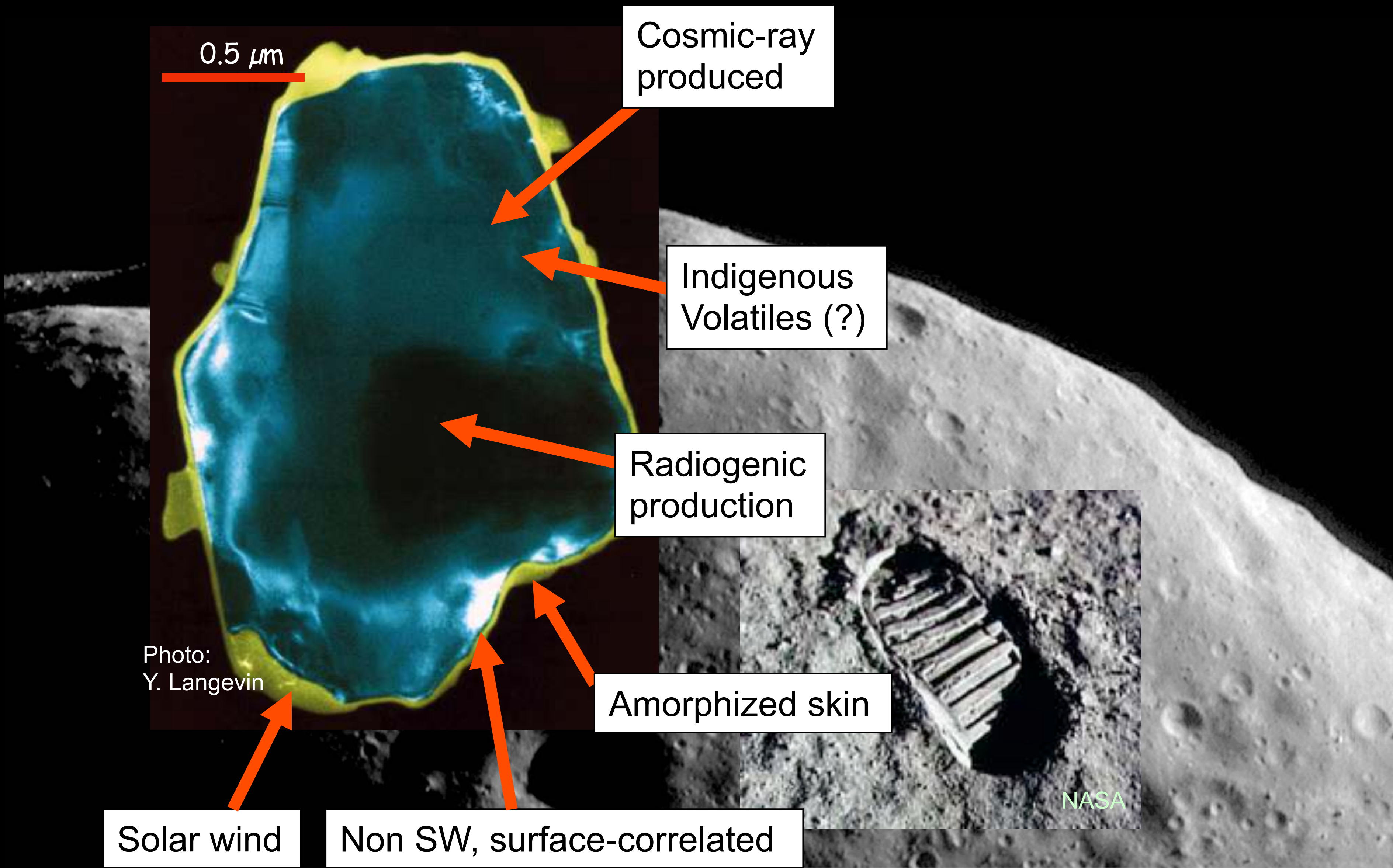
3. What are the physical properties and evolution of the building blocks of terrestrial planets ?

Regolith: the lunar soil legacy

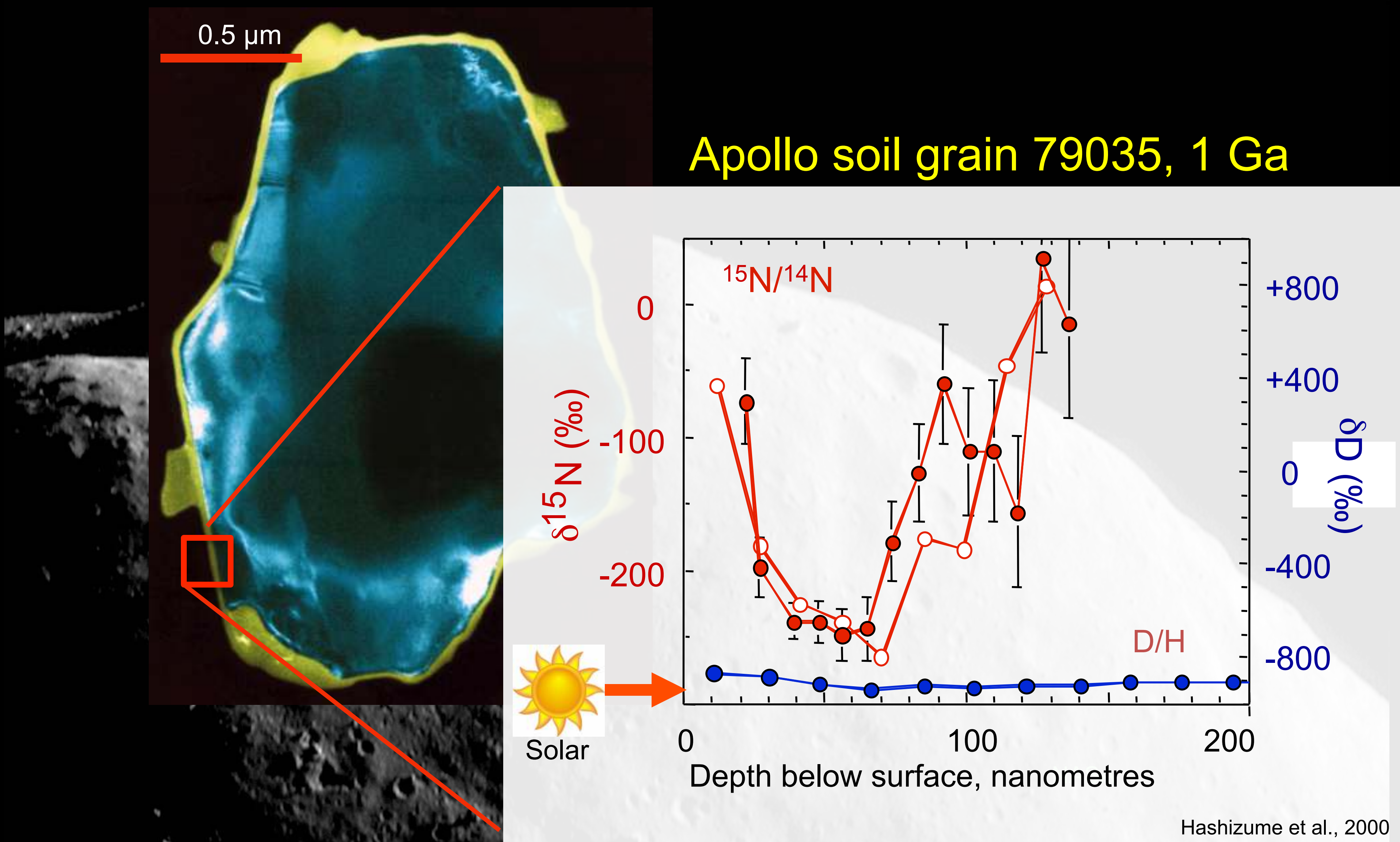
NASA

Eros, NEAR (NASA/JHU/APL)

A world in a grain : investigating asteroid processing in dust



A world in a grain : investigating asteroid processing in dust



Hashizume et al., 2000

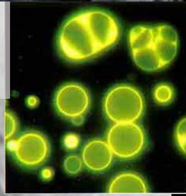
4a. How do organics in primitive NEAs relate to life on Earth ?

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

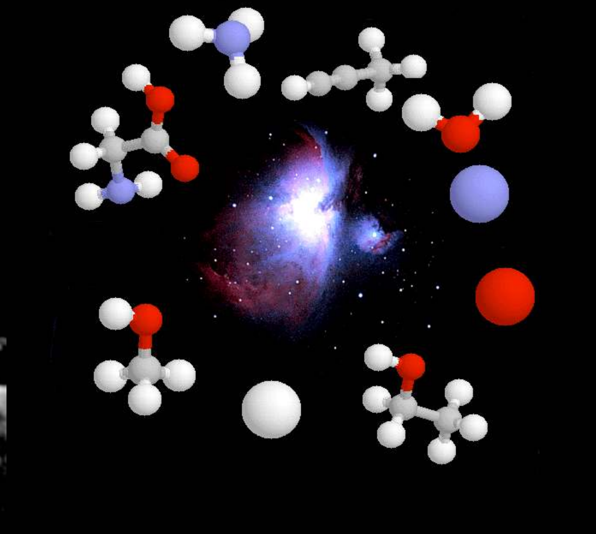
Organics from space

Extraterrestrial delivery via small bodies seeded the young Earth during in its early history: precursor material for life ?

Early Earth's chemistry

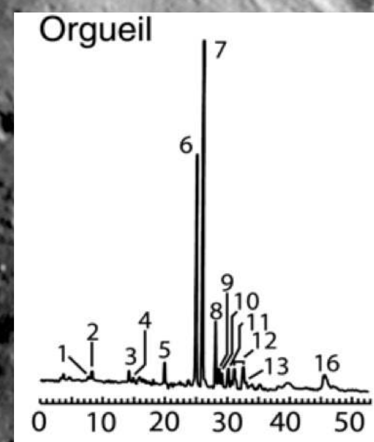


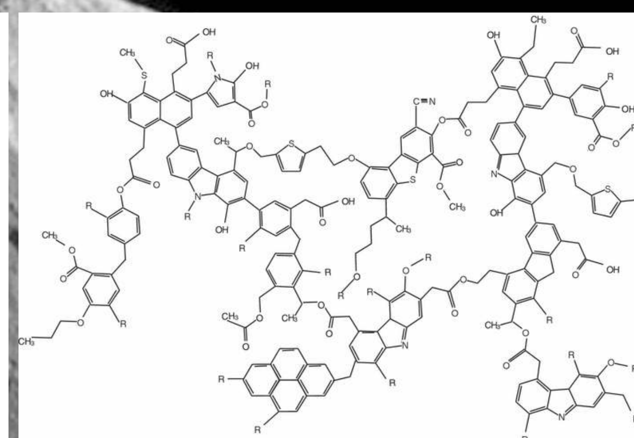
Insights into cosmic carbon chemistry



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

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

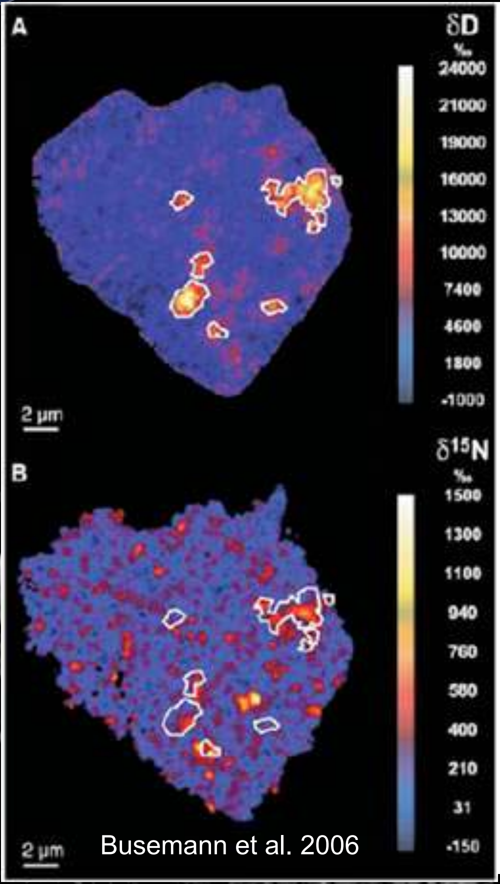




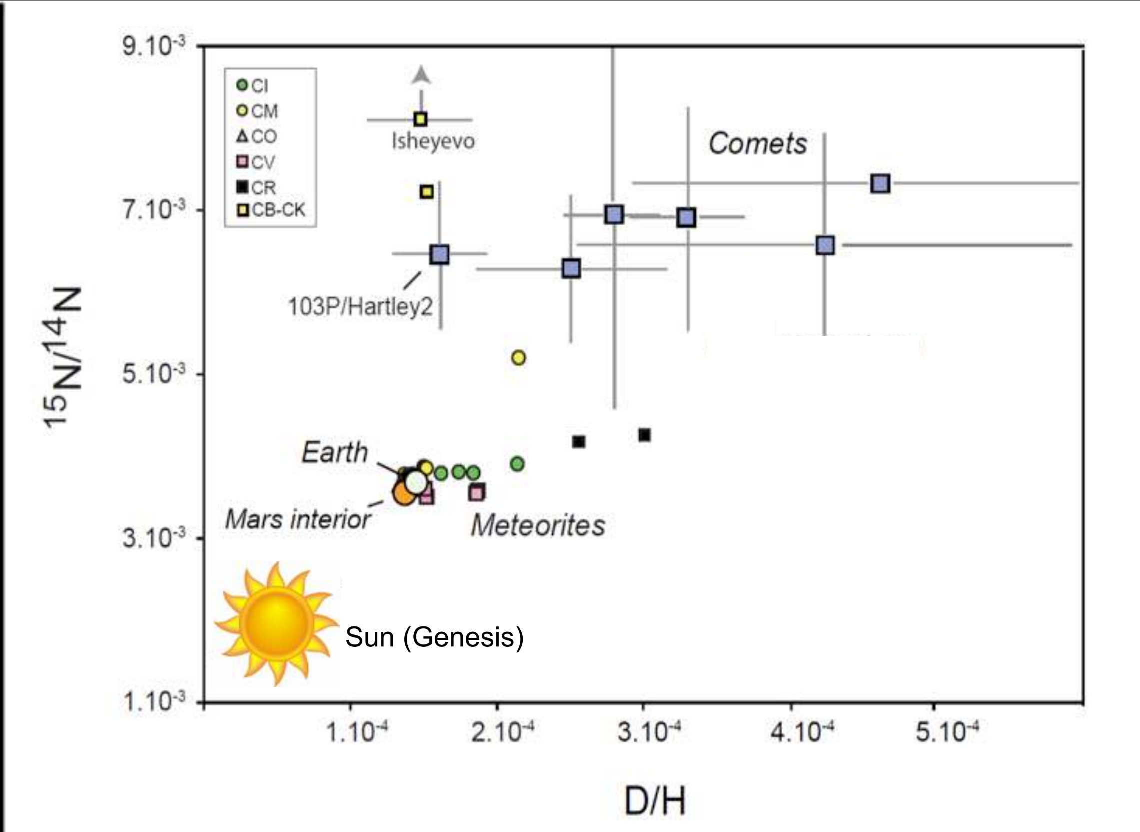
Ehrenfreund et al. 2001

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 ?



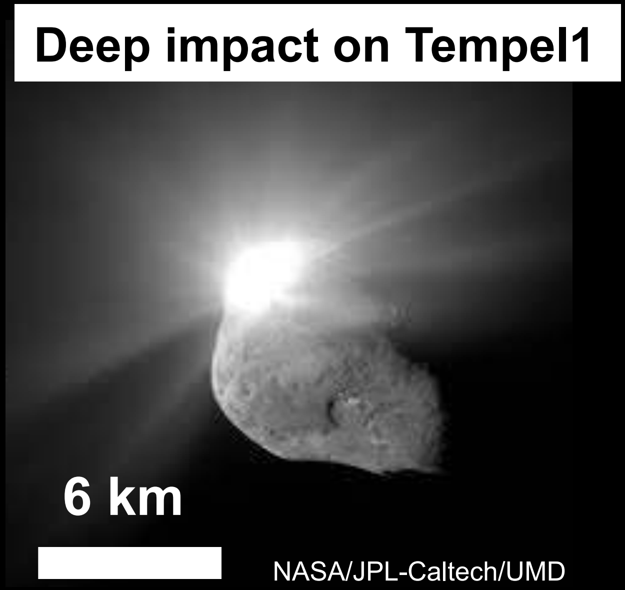
Busemann et al. 2006

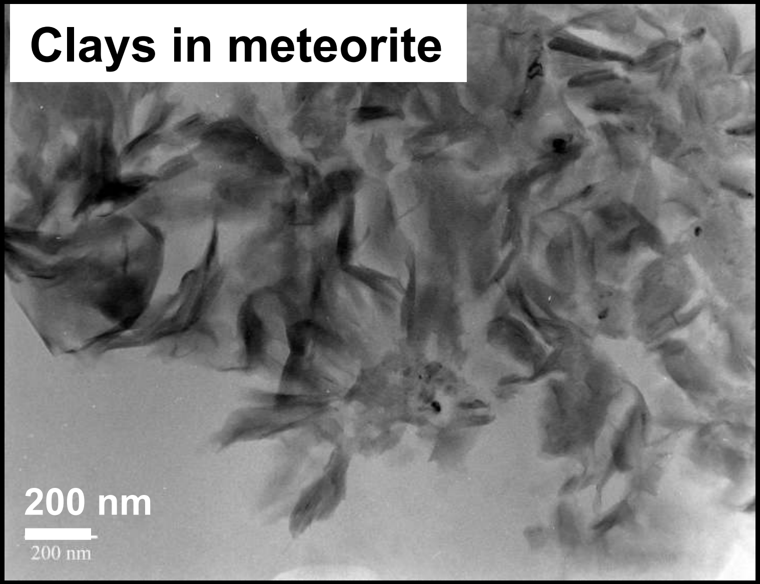


Marty, 2012

- 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?





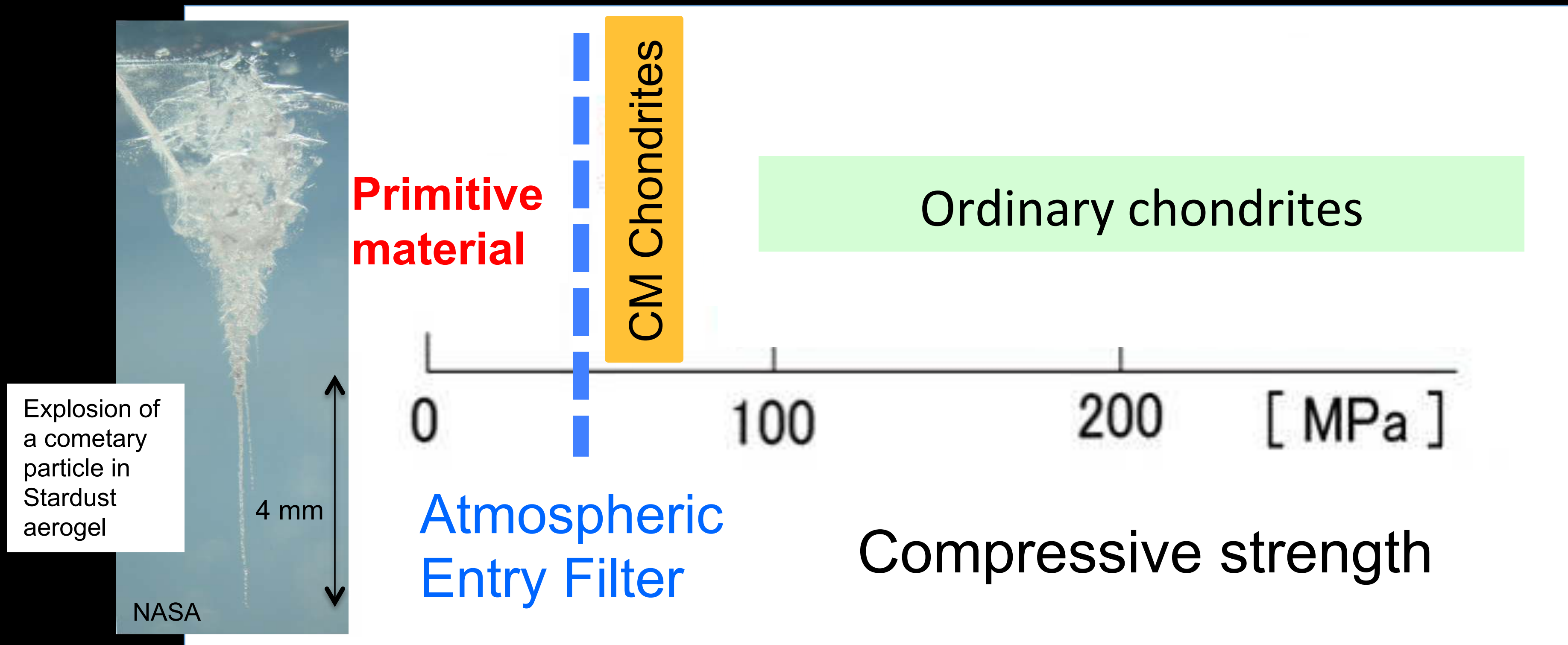
The computed water/rock ratio in meteorites (representative of asteroids?) is up to 1
(Clayton 1984, Young et al. 2002)

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



Tsuchiyama et al. 2008

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

Why do we need to return samples when we have meteorites ? Terrestrial contamination

Photo: Getty

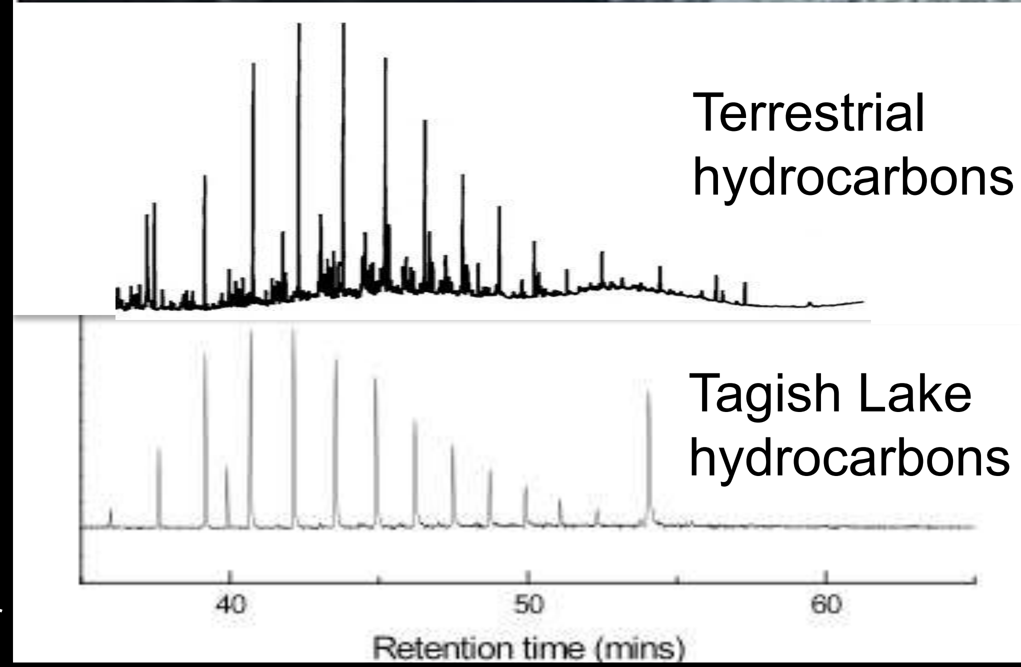
Why do we need to return samples when we have meteorites ?

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



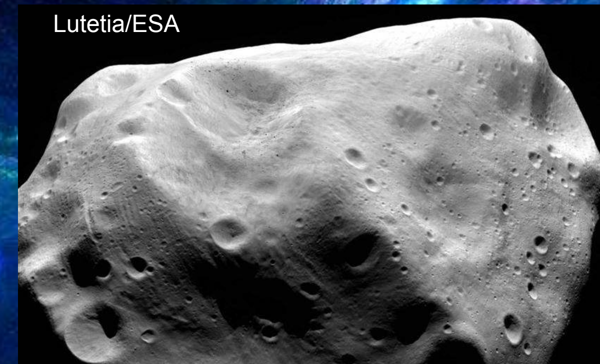
Credit: I. Gilmour

Near Earth Asteroid Sample Return

MarcoPolo-R

MarcoPolo-R will:

- Return ~100g of sample for high precision lab analysis
- Characterize a primitive Near-Earth Asteroid at multiple scales

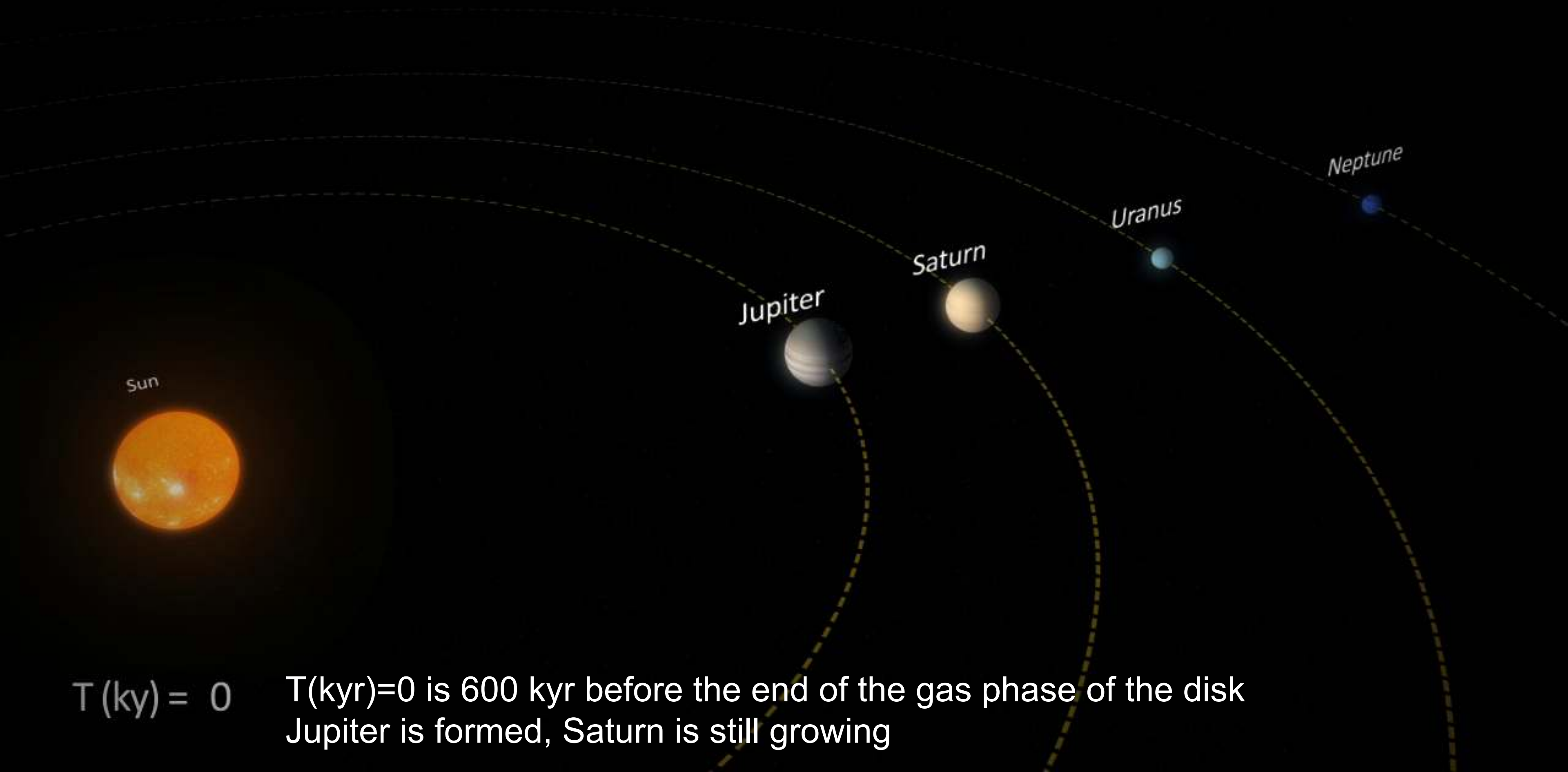

Lutetia/ESA


NASA


M. Champenois

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(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)

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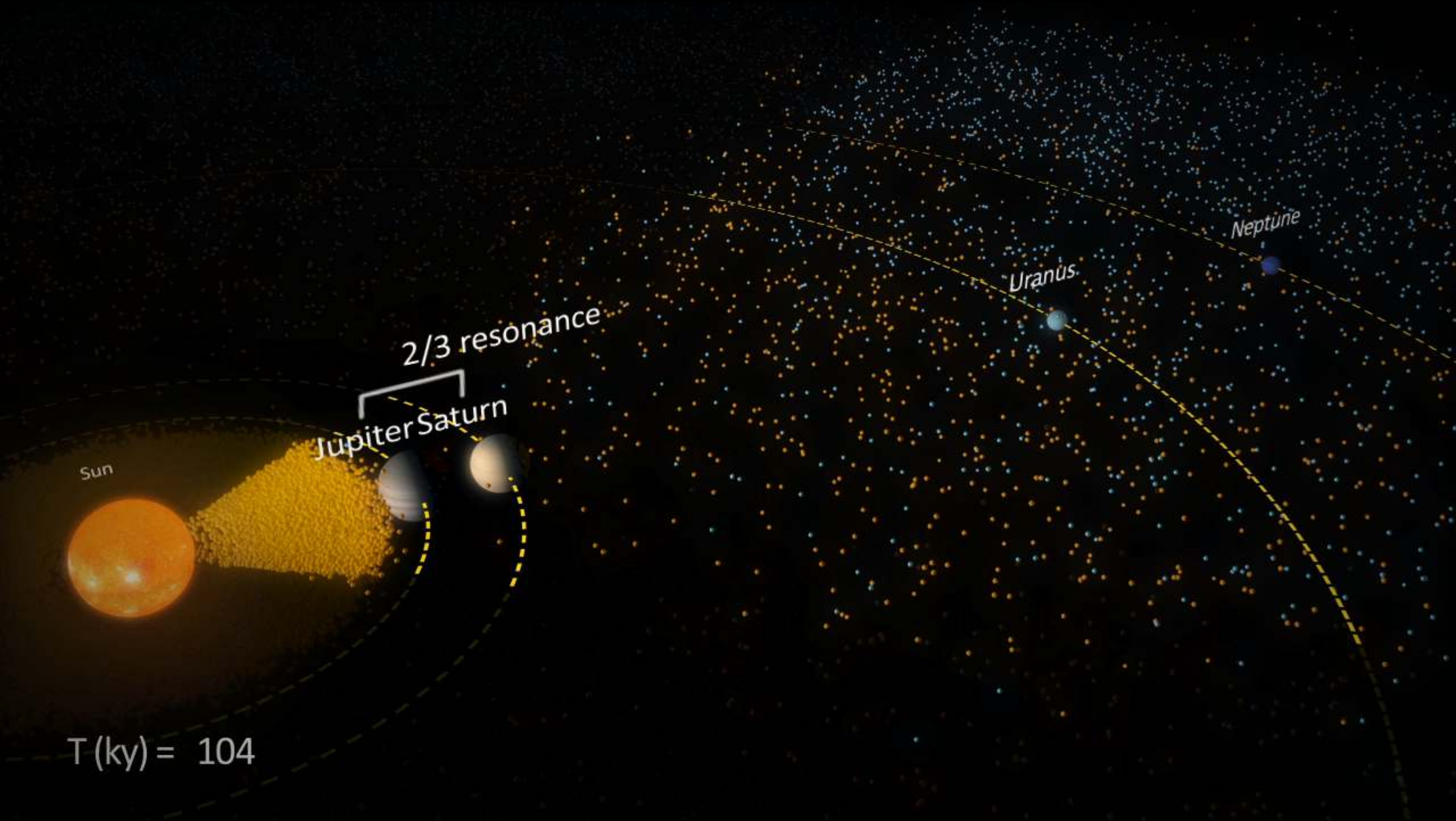

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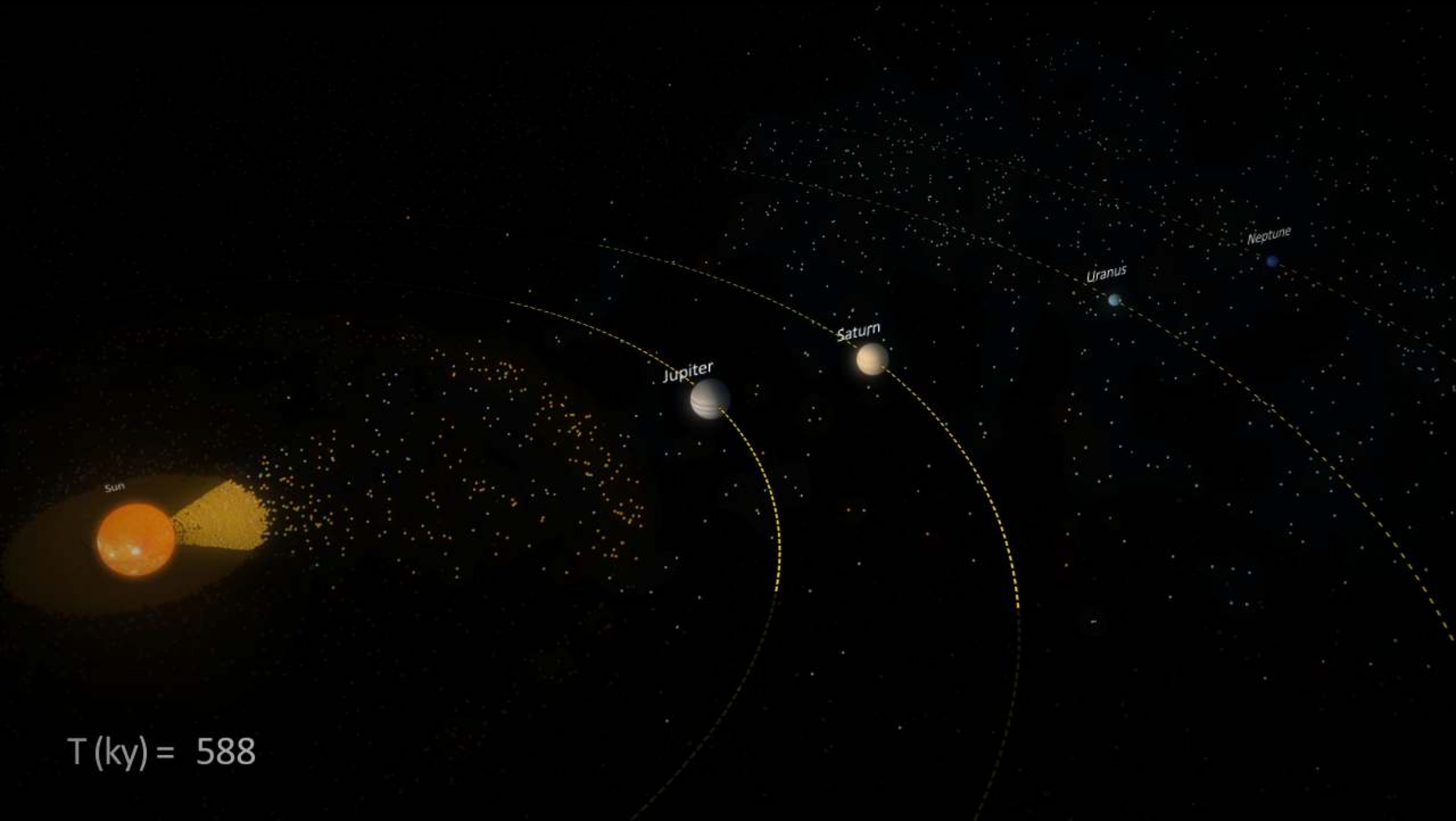

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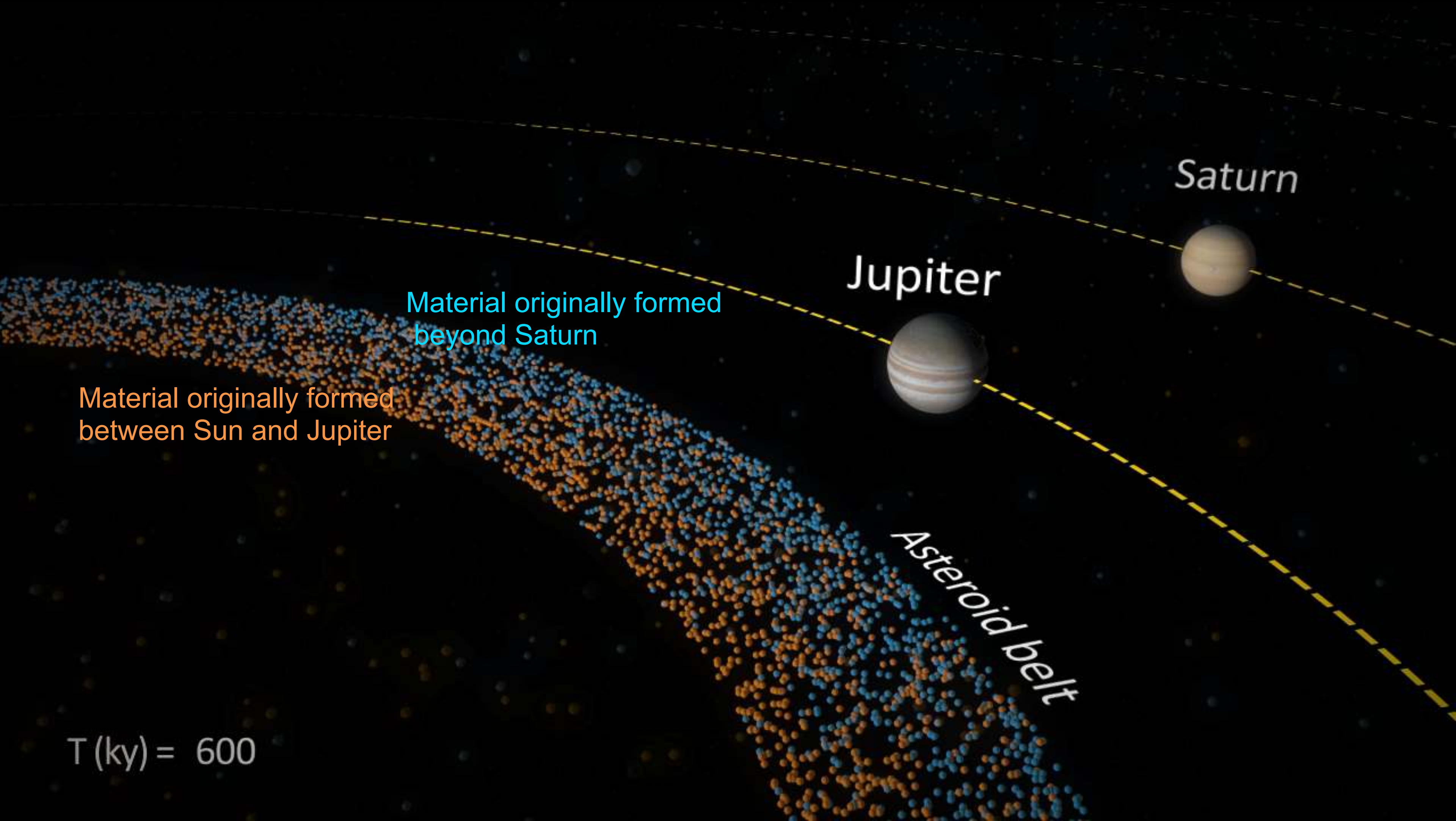
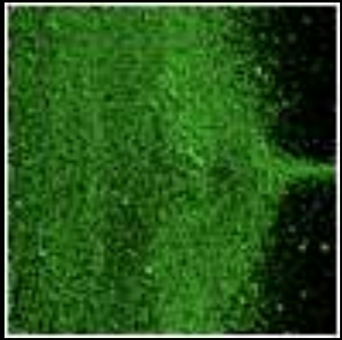
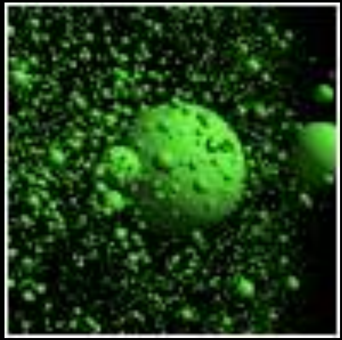


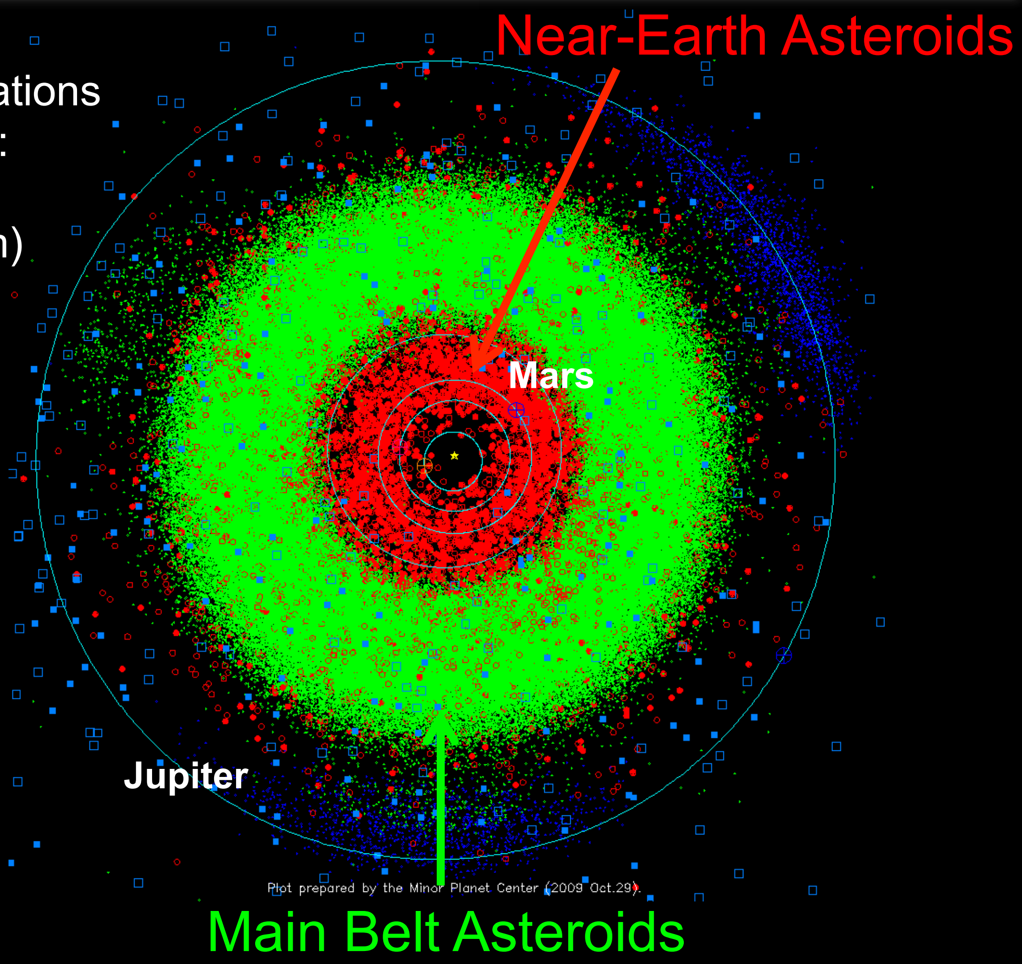
Where to take a sample from an asteroid?





From numerical simulations of asteroid disruptions: Most small asteroids (>200 m and < 100 km) are rubble piles

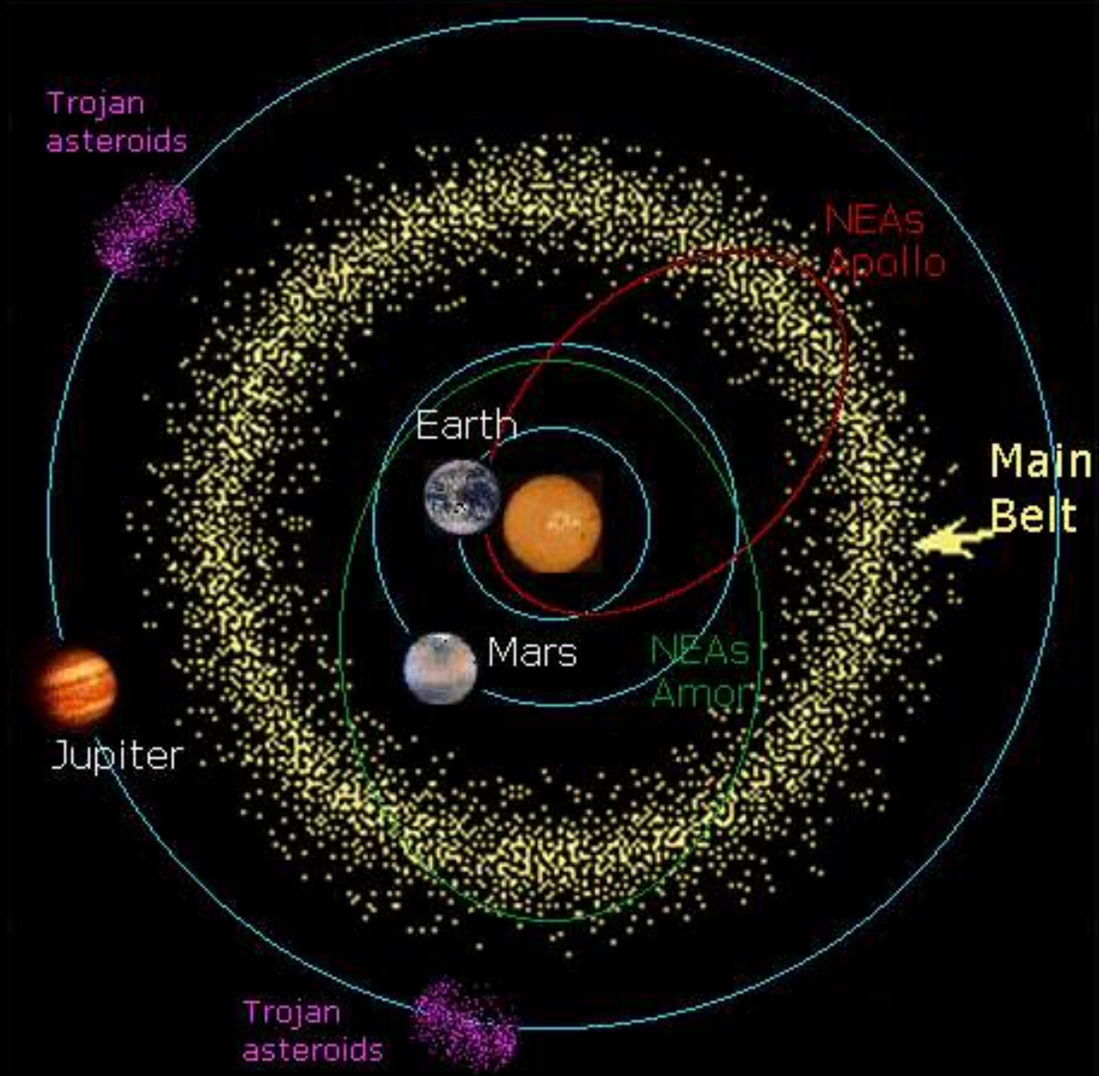
Michel et al. 2001, 2003



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

Why a NEA?

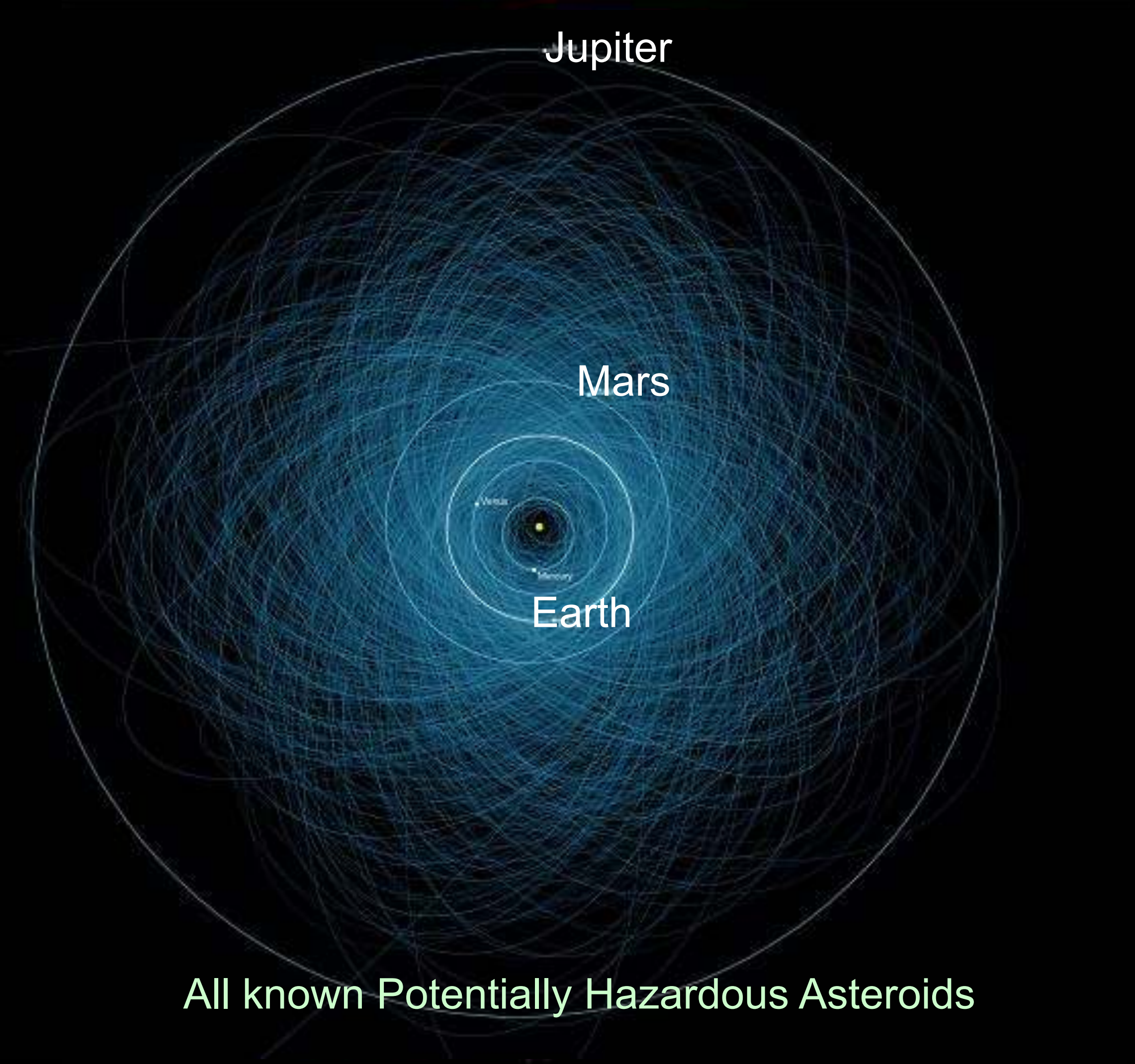
- NEAs are the most accessible targets for primitive material sample return



Why a NEA?

- NEAs are the most accessible targets for primitive material sample return

- Some NEAs are potentially hazardous



All known Potentially Hazardous Asteroids

© NASA

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

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

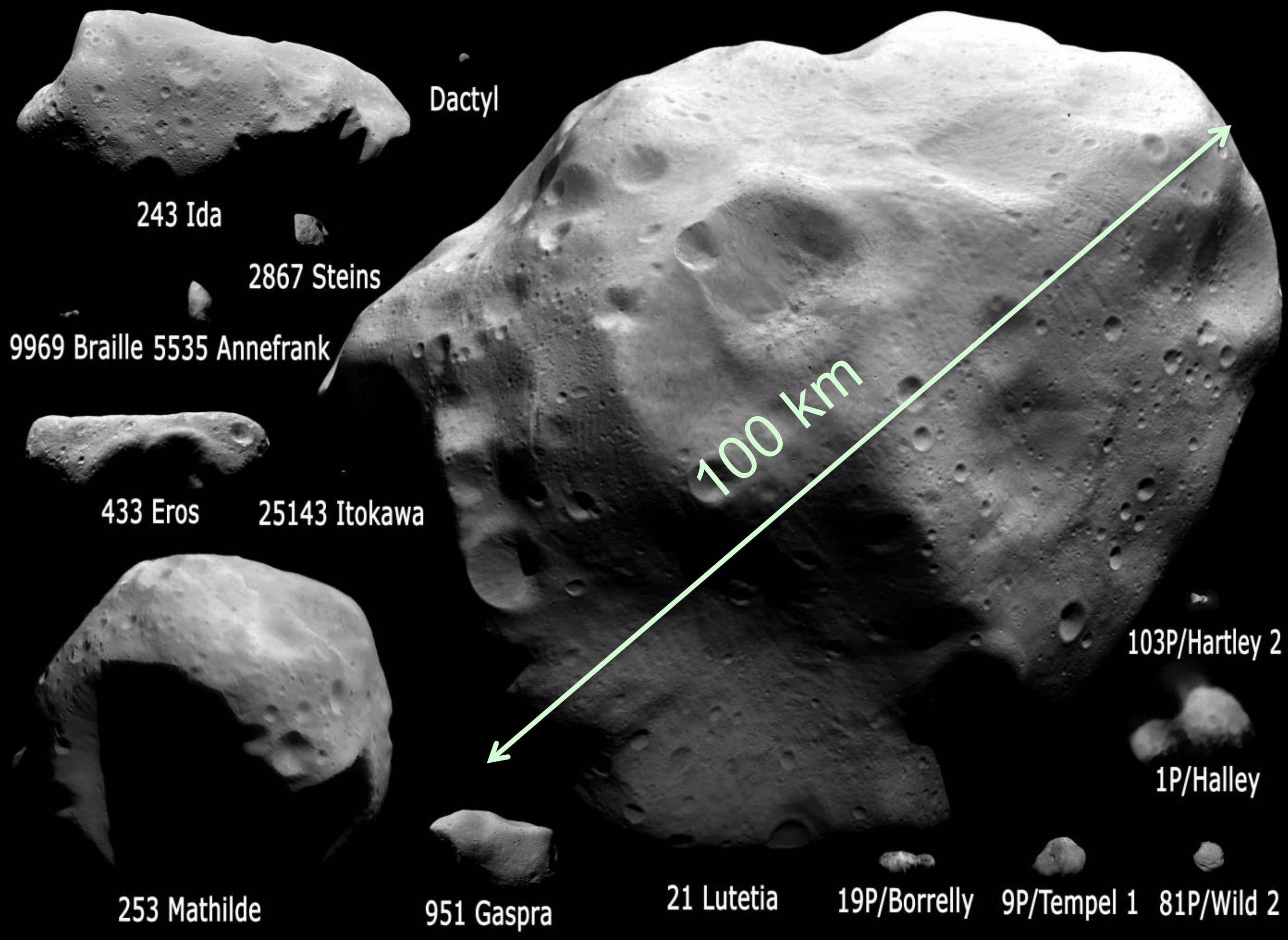
~1.2 km

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

Mitigation strategies need better knowledge of NEA properties

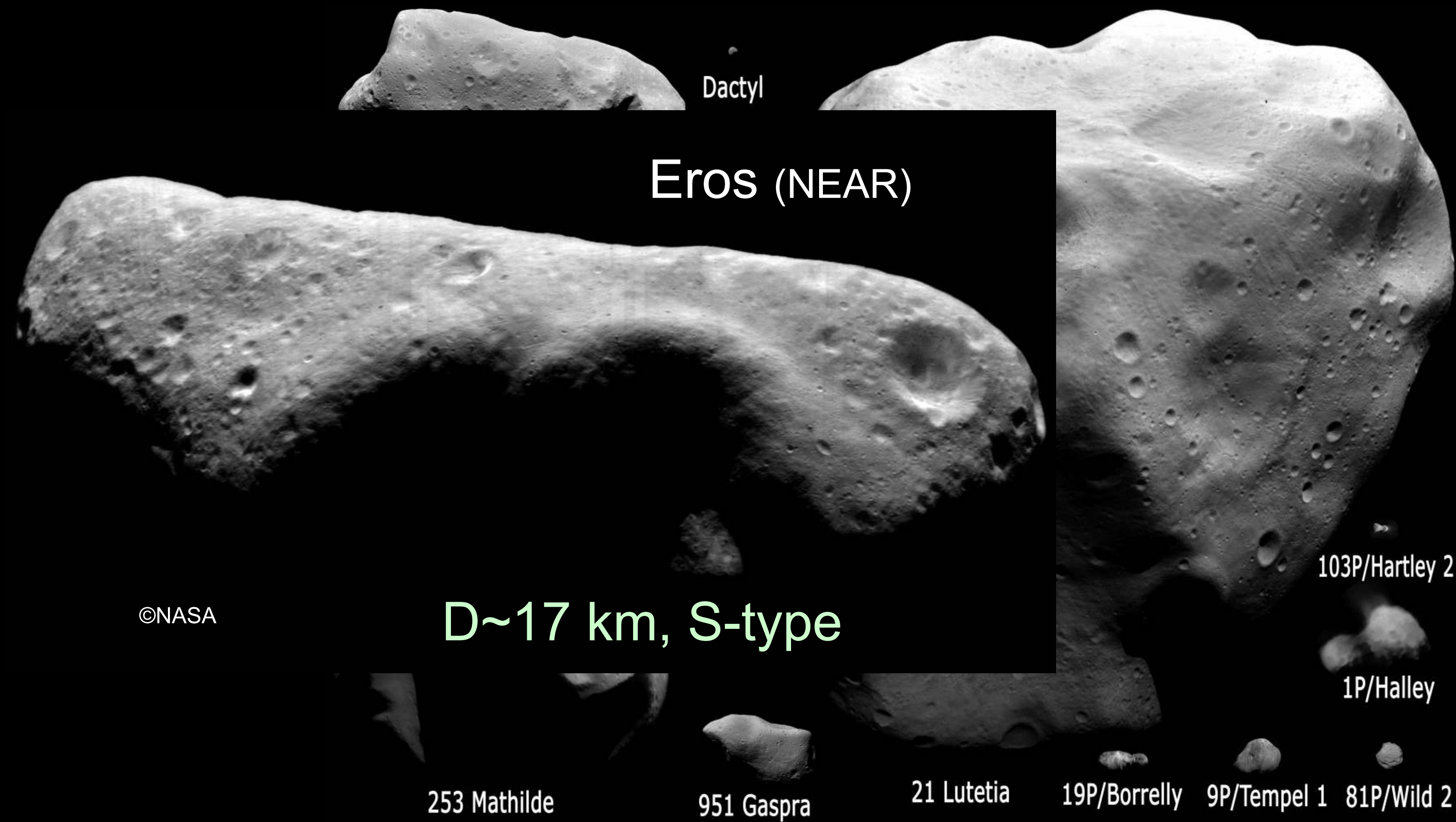
Small body populations

A wide variety of physical & compositional properties



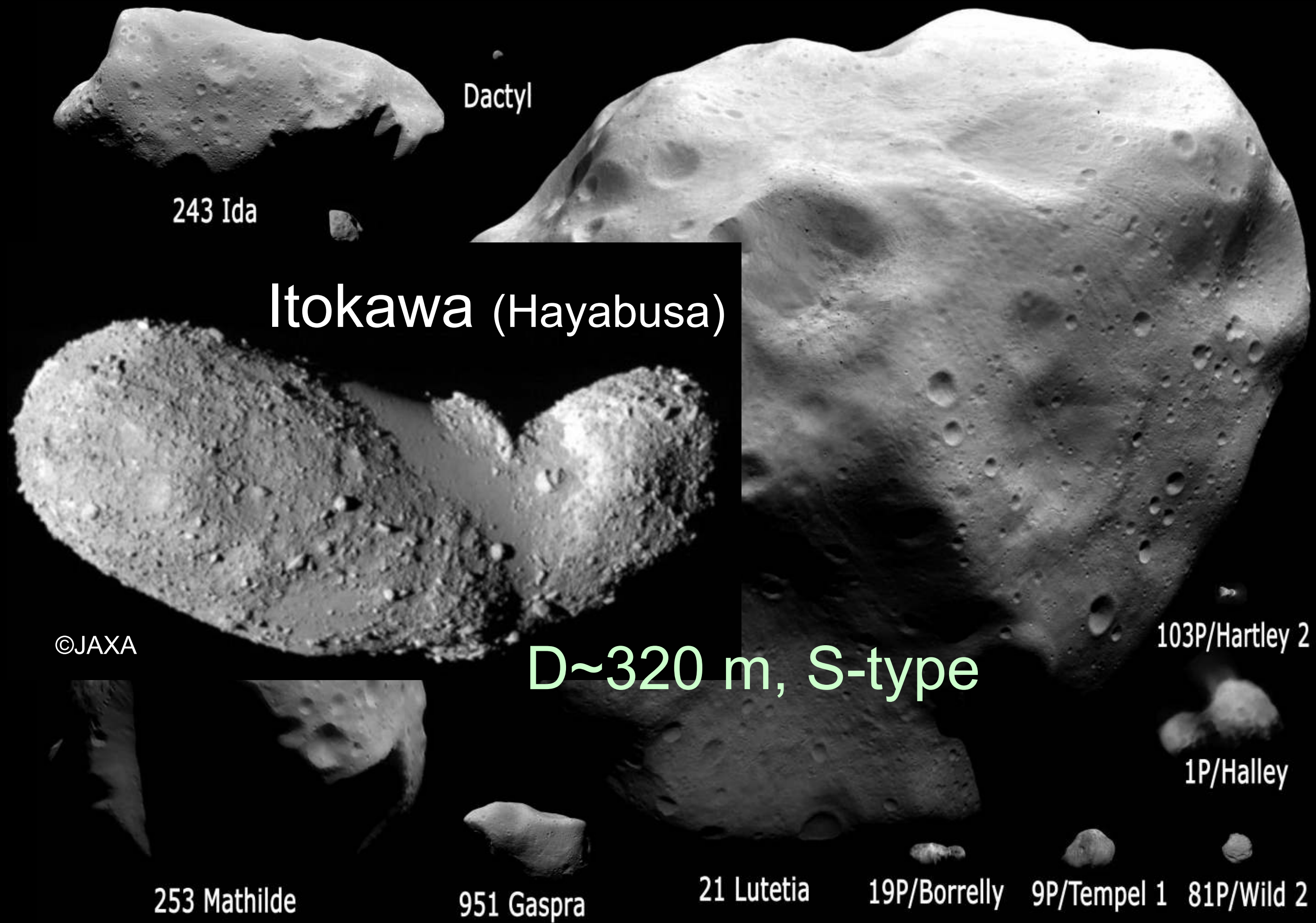
Small body populations

A wide variety of physical & compositional properties



Small body populations

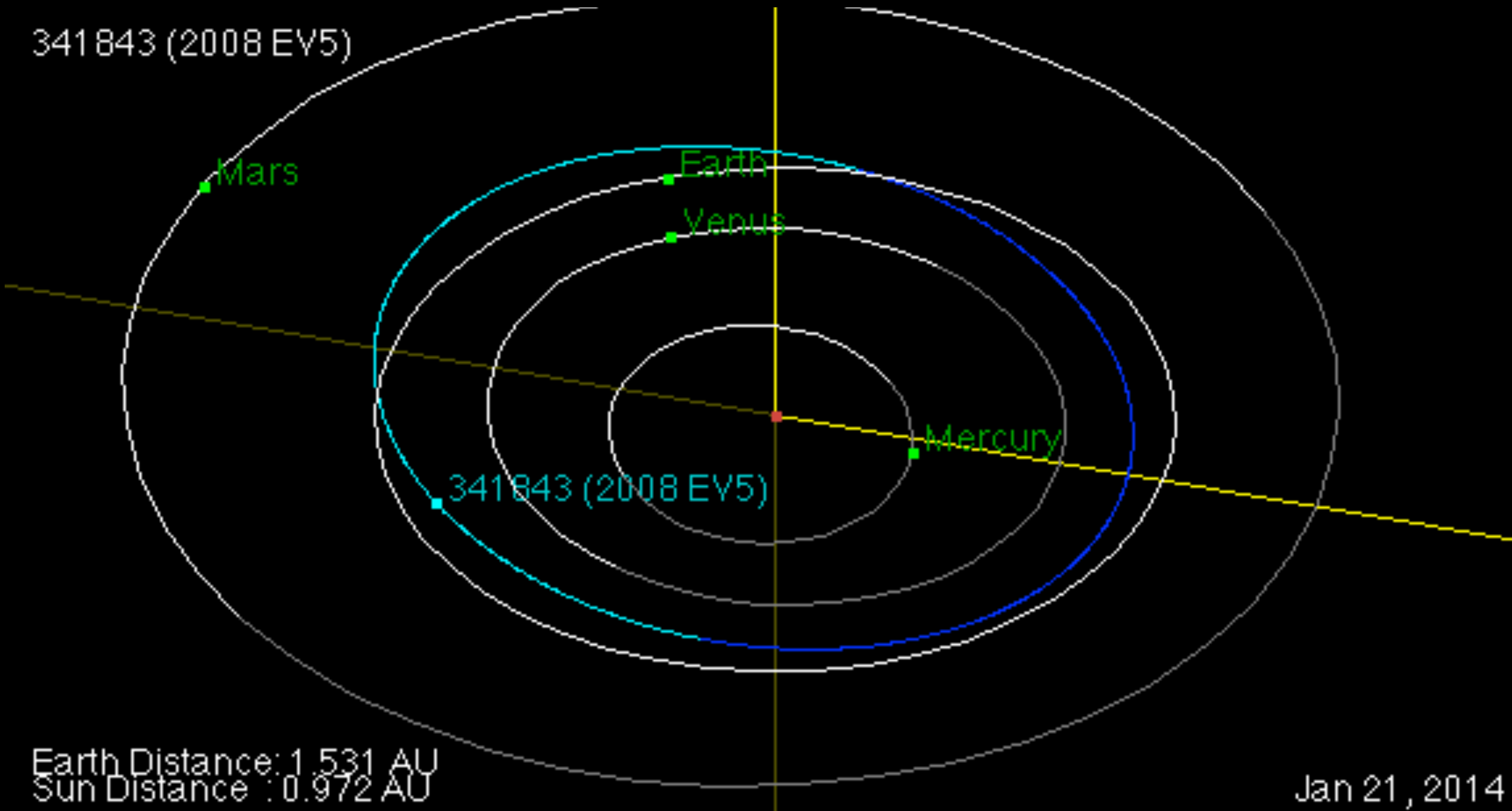
A wide variety of physical & compositional properties



We do not have yet detailed information on a primitive NEA

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)

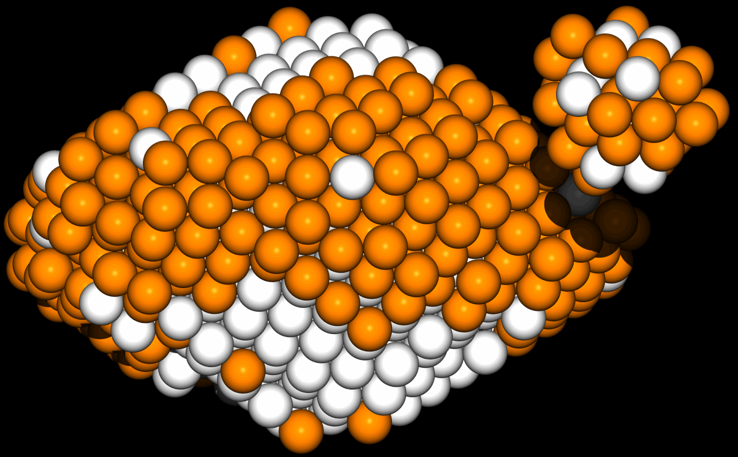
Radar observations provide unparalleled knowledge of 2008 EV5

Busch et al. 2011

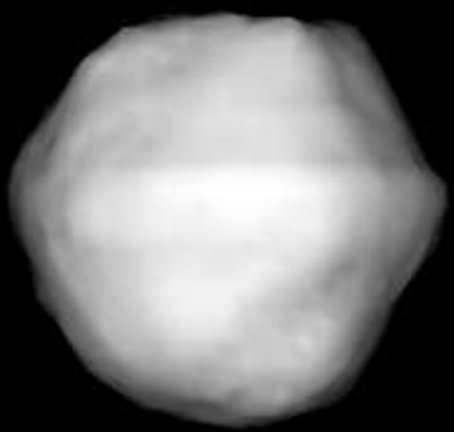
- 400 ± 50 metre oblate spheroid
- Period = 3.725±0.001h
- Albedo: 0.10-0.12
- No evident large blocks (at 7.5 m-resolution)

2008 EV5 has a top shape, a ridge and a rotation period similar to that of binary's primaries

YORP spinup sims, Walsh et al. 2008



Binary 1999 KW_4 radar model, Ostro et al. 2005



Binary 2004 DC
Taylor et al. 2008, ACM

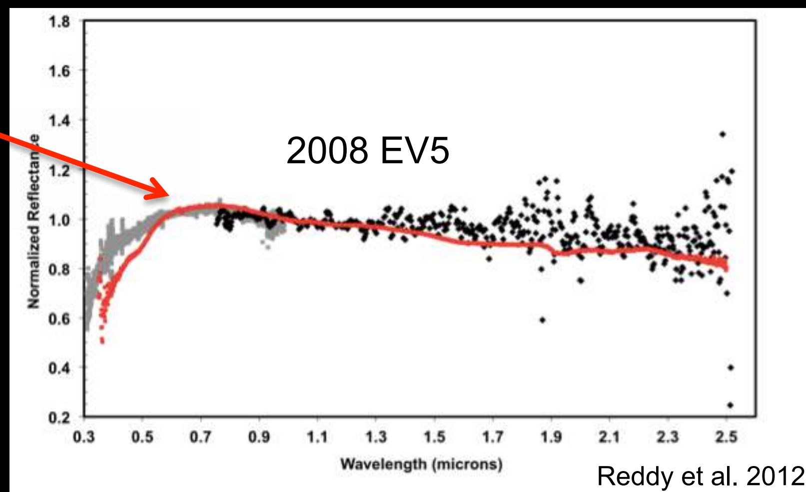
Single
2008EV5
Busch et al. 2011

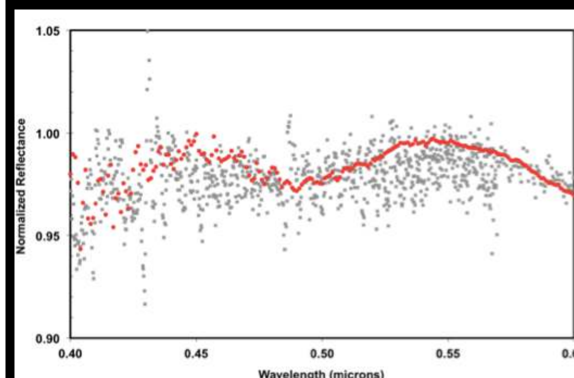
Unique science value of 2008 EV5

- Spectral type: belongs to the C complex

0.48-µm absorption band indicative of aqueous alteration

CI meteorite
Orgueil





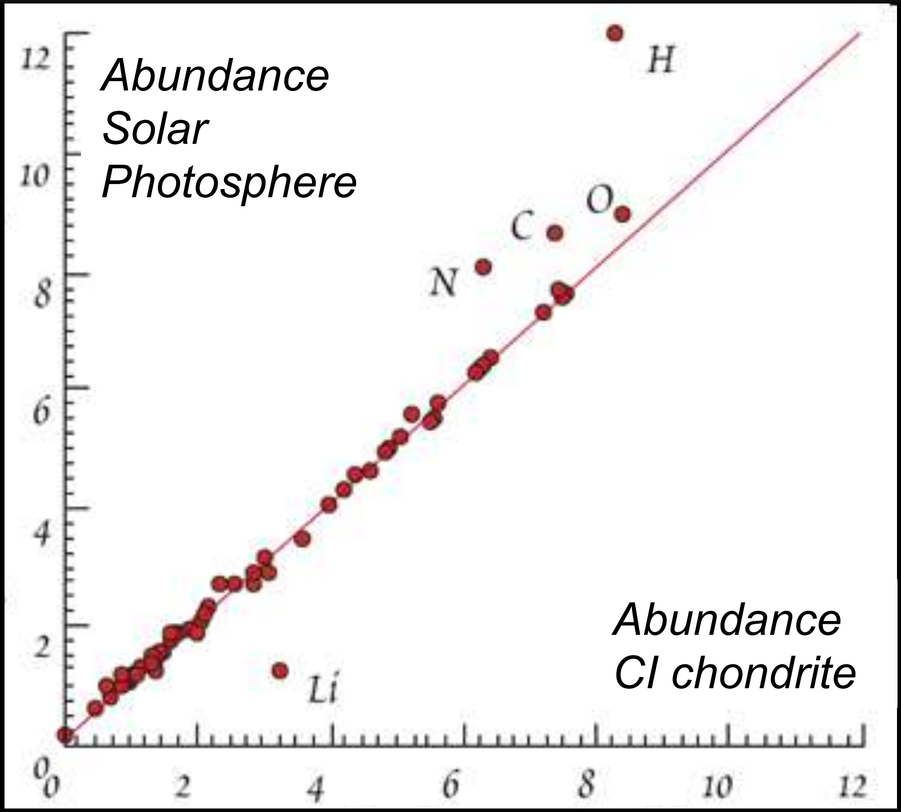
Parent body likely accreted in
an unfractionated volatile rich region

Unique science value of 2008 EV5

Lodders 2003

CI meteorite
Orgueil

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



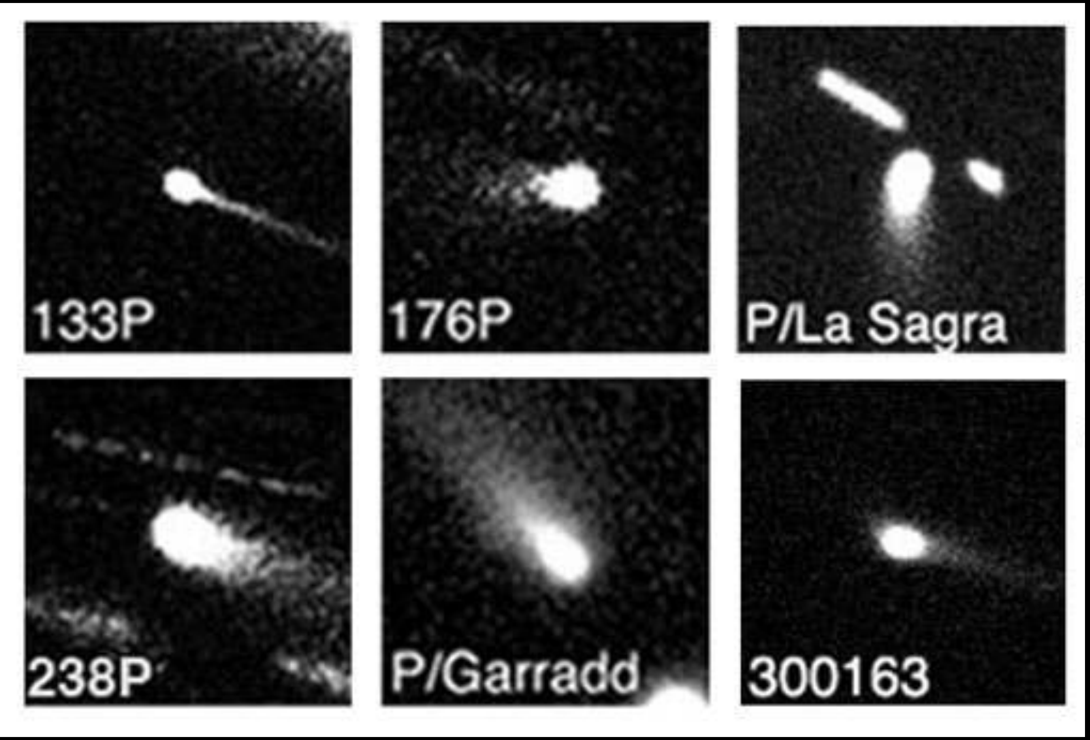
Parent body likely accreted in
an unfractionated volatile rich region

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

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

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

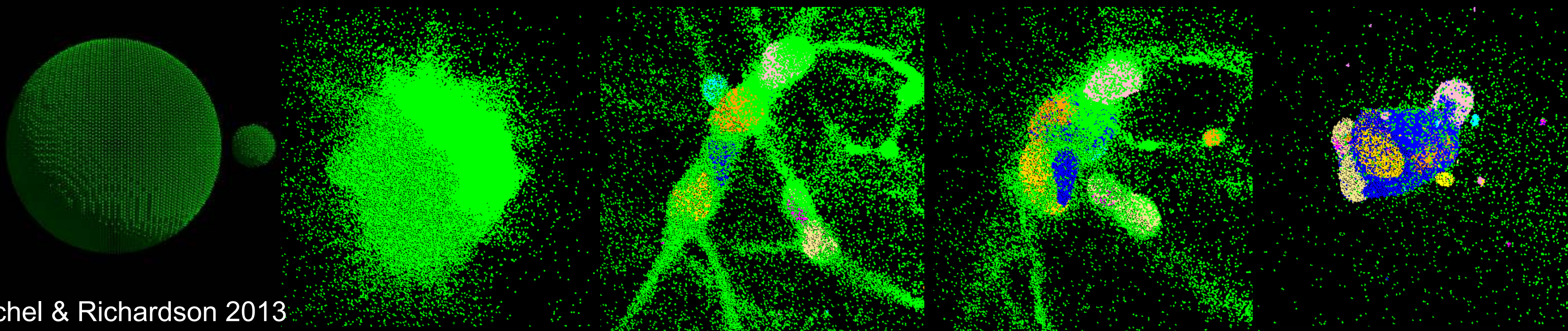
(Kueppers et al.. 2014)

- Albedo of Ceres = 0.10 similar to 2008 EV5!

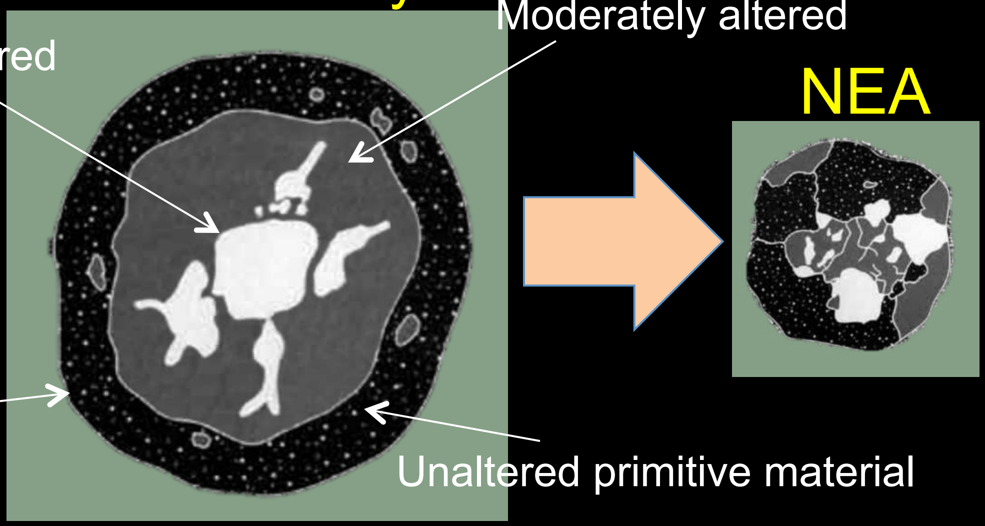
EV5 may be a transitional object

Formation of 2008 EV5

Disruption of a parent body and reaccumulations



Michel & Richardson 2013

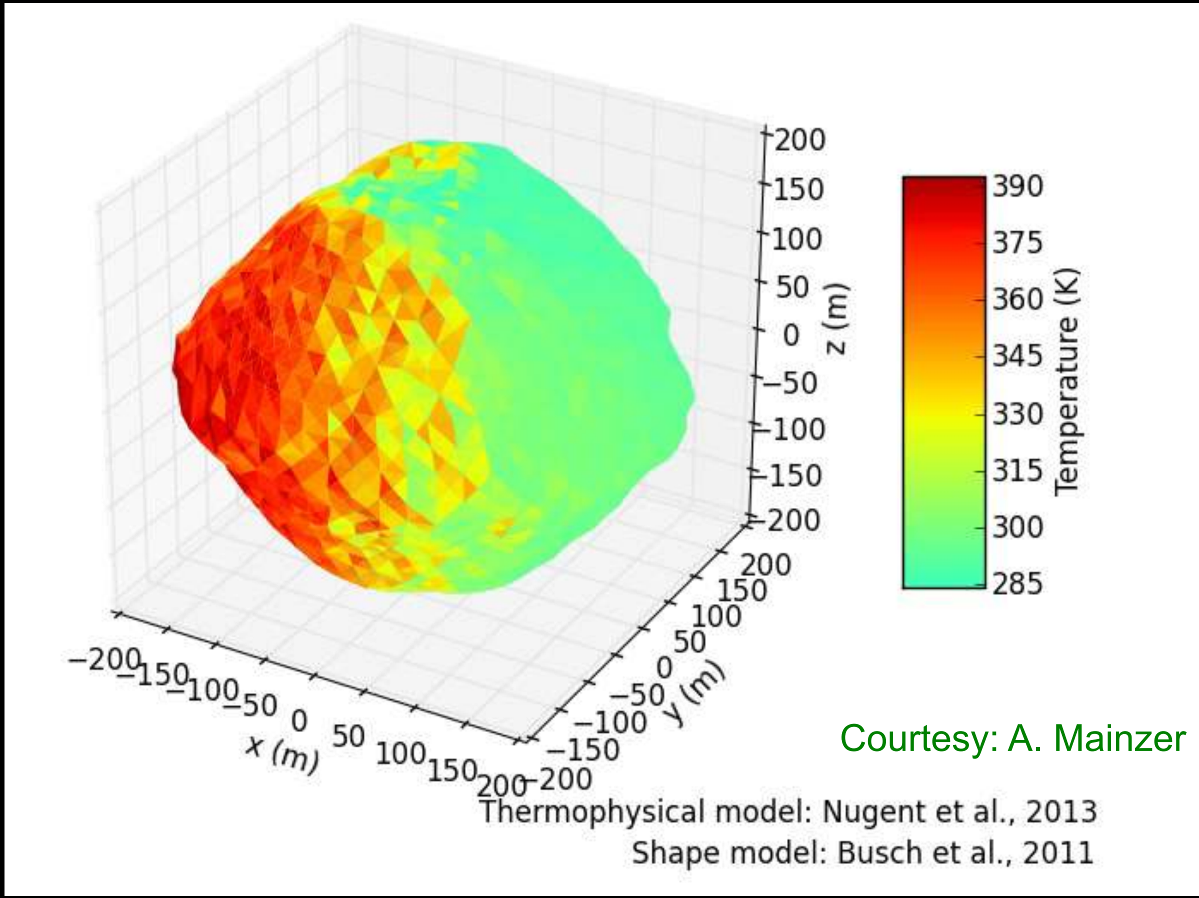


JAXA

A NEA contains parent components that do not survive atmospheric entry

Regolith is a mixture of some or all components

Thermophysical modeling of 2008 EV5



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

Thermal Inertia Γ of ≈ 450 +/- 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

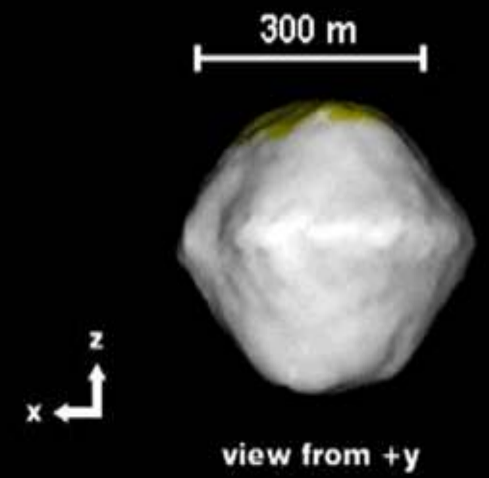
Delbo et al. 2013

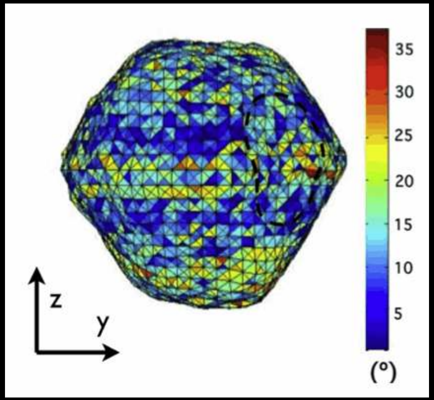
2008 EV5
An ideal target for sample return

- 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**

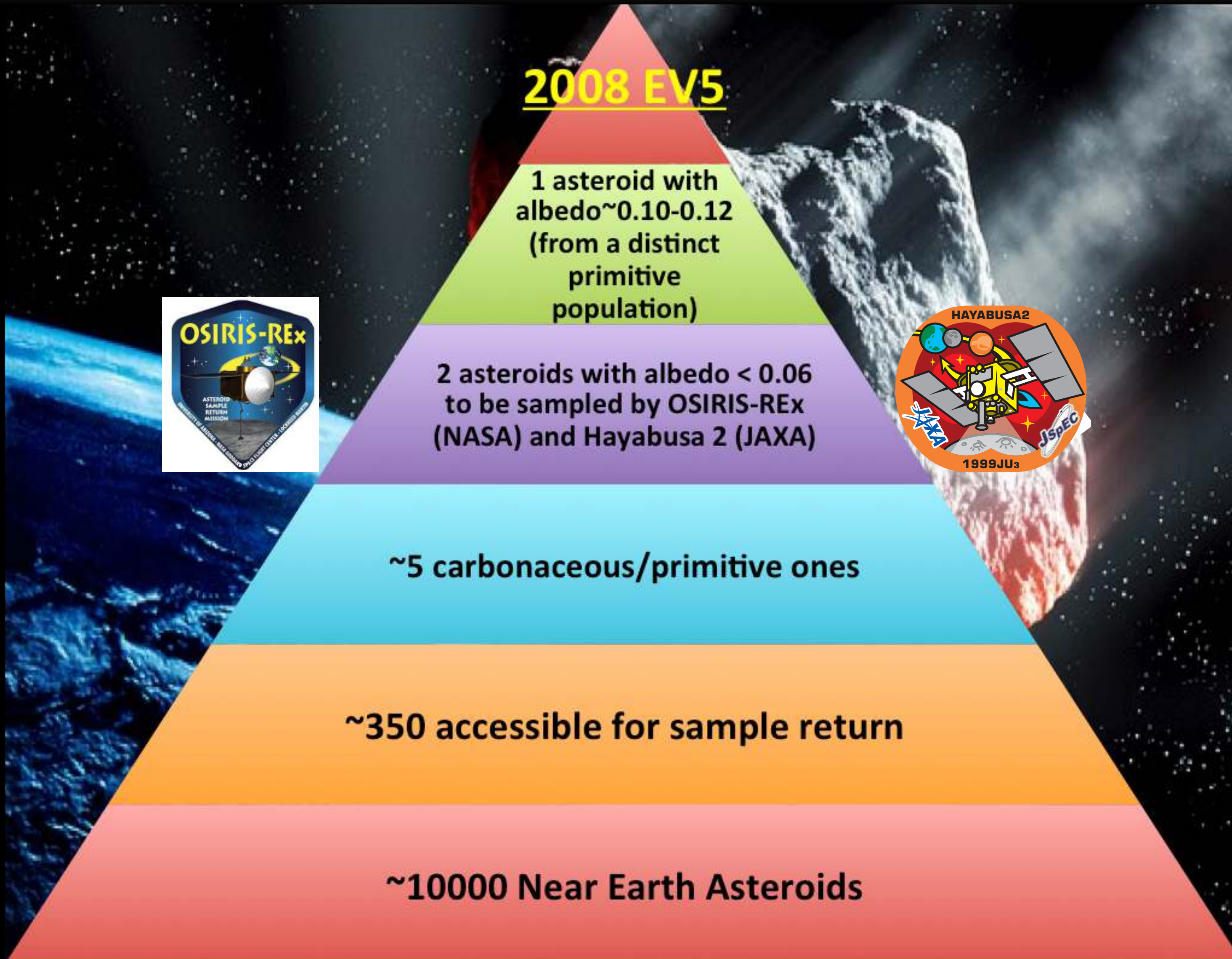
- Study of a Potentially Hazardous Asteroid is **strategically important** to space agencies and international institutions concerned with hazard and mitigation



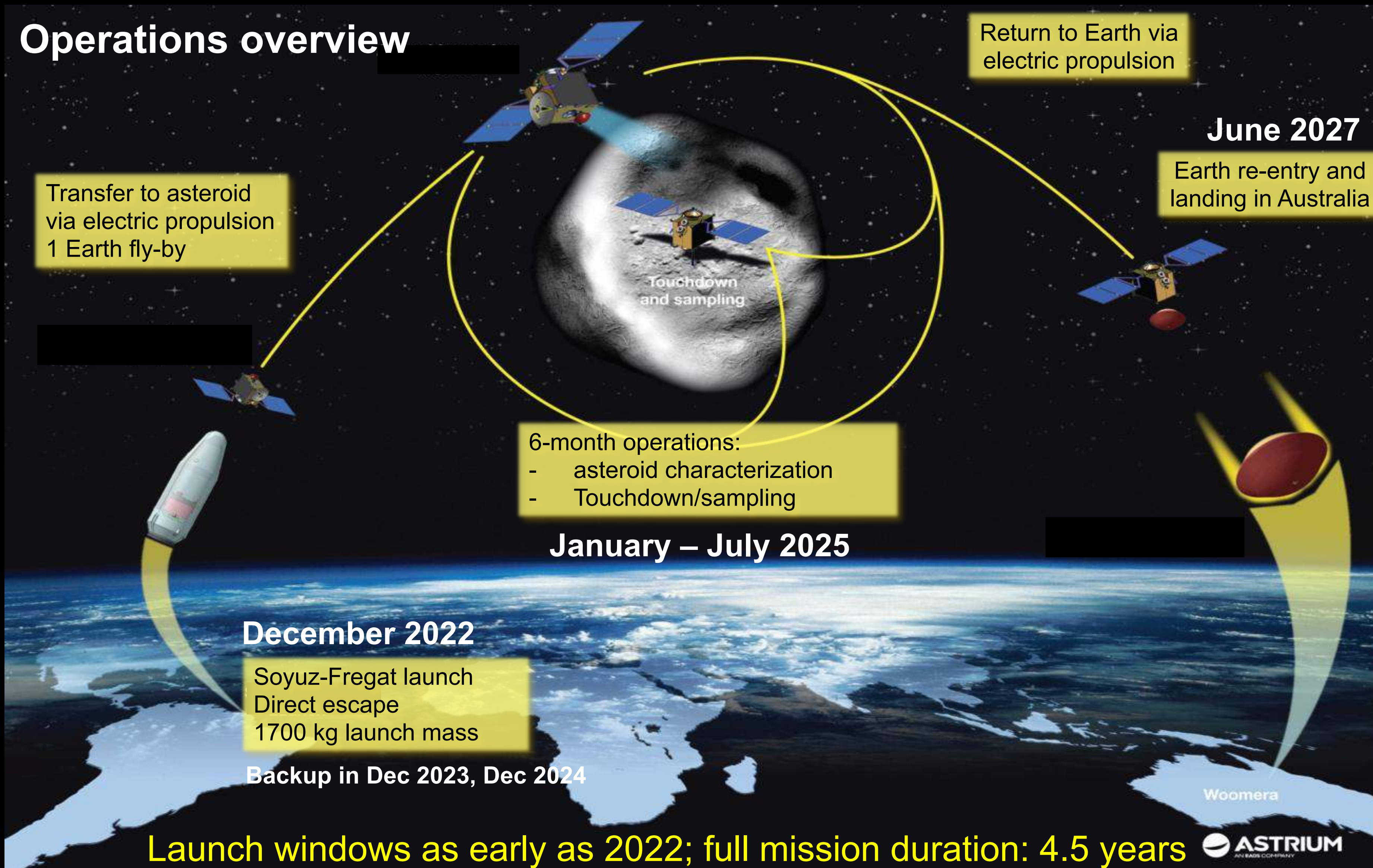


Busch et al. 2011

2008 EV5 rises to the top of the asteroid charts!



Mission scenario



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

Science payload

Name	Type
MaNAC	Narrow Angle Camera
CUC	Close-up Camera
MaRIS	Visible/near Infrared imaging Spectrometer
THERMAP	Mid-infrared spectro imager
RSE	Radio Science Experiment
VISTA-2	Thermo gravimetric measurement sensor

- **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

Name	Type
MaNAC	Narrow Angl
CUC	
MaRIS	
THERMAP	
RSE	ence Experiment
VISTA-2	Thermo gravimetric measurement sensor

allows for direct comparison with ground-based telescopic data of the entire asteroid population!!

- **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

Sampling tool development

Brush-wheel sampler concept, Credit: AVS

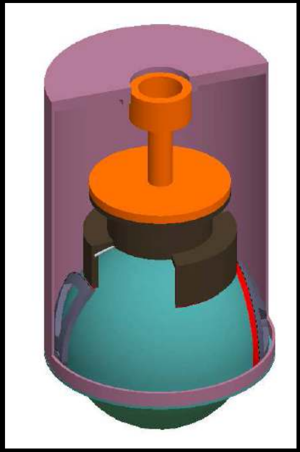
Top-level requirements:

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

Parallel sampling tool developments

0-g test in 2014

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



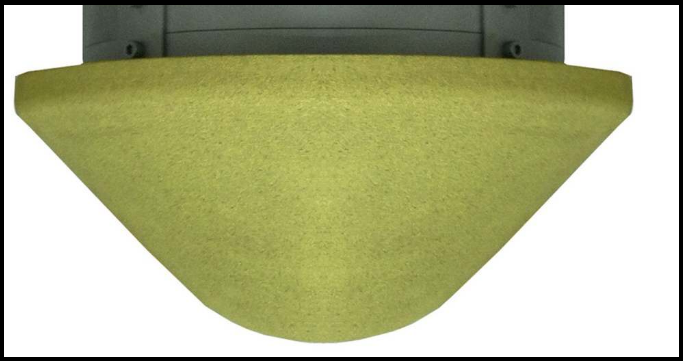
Bucket sampler concept, Credit: Selex-ES

NASA funded study to MarcoPolo-R

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

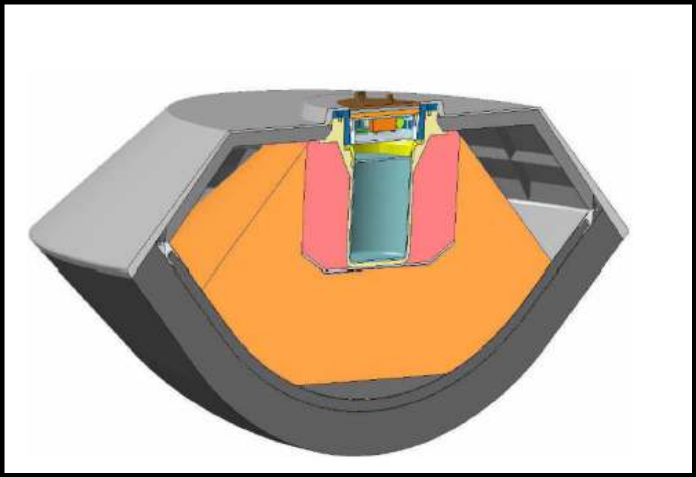
http://us-marcopolor.jhuapl.edu

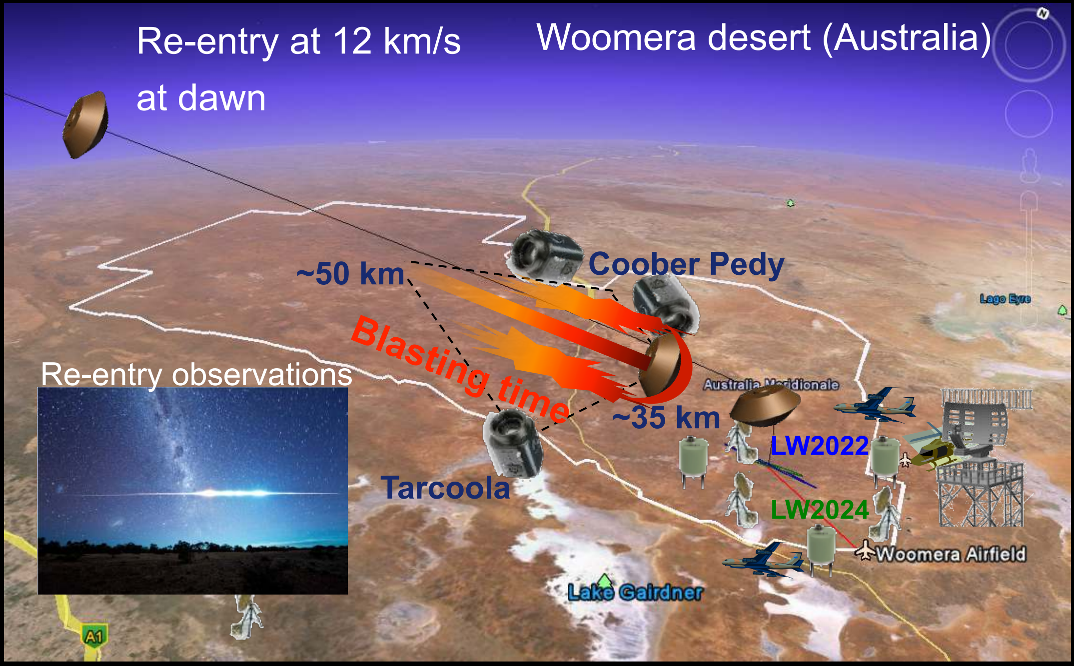
Earth Re-entry Capsule and recovery



Heat shield prototype (Astrium Ltd)

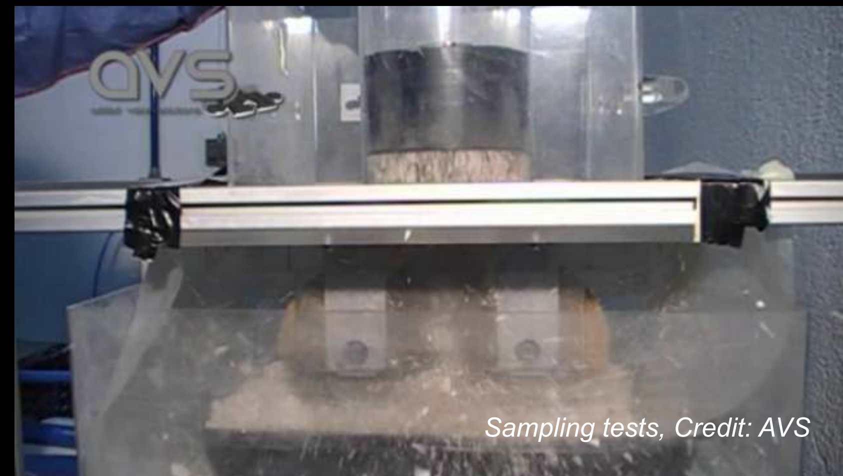
- Fully passive capsule, ~ 500 s re-entry
- Landing ellipse knowledge ~ a few km
- Safest and lowest cost approach





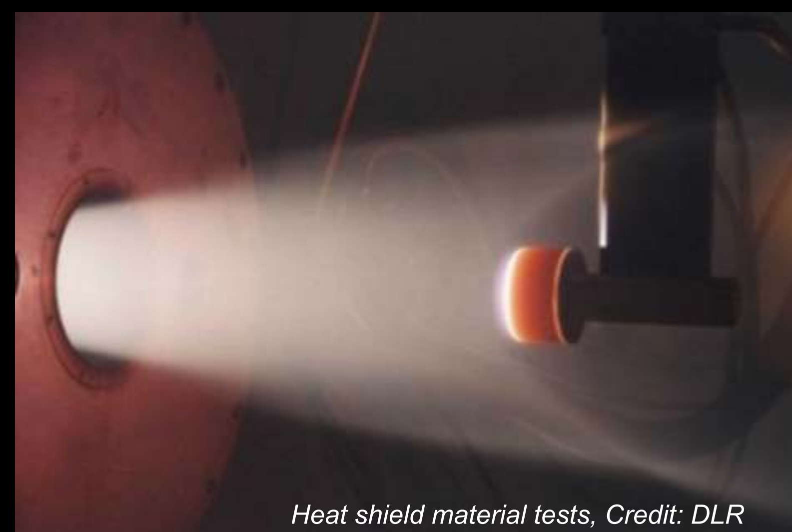
Technologies

- 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



Sampling tests, Credit: AVS

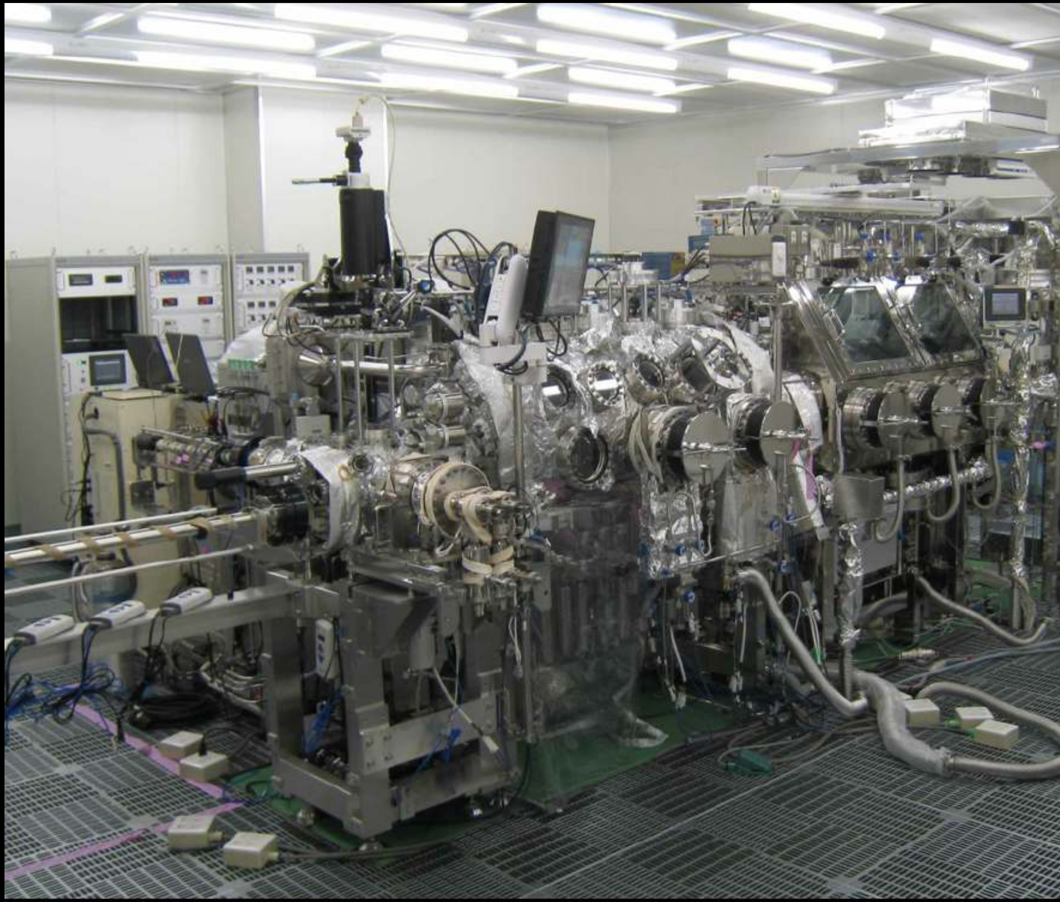

GNC tests, Credit: GMV


Heat shield material tests, Credit: DLR

Curation Facility

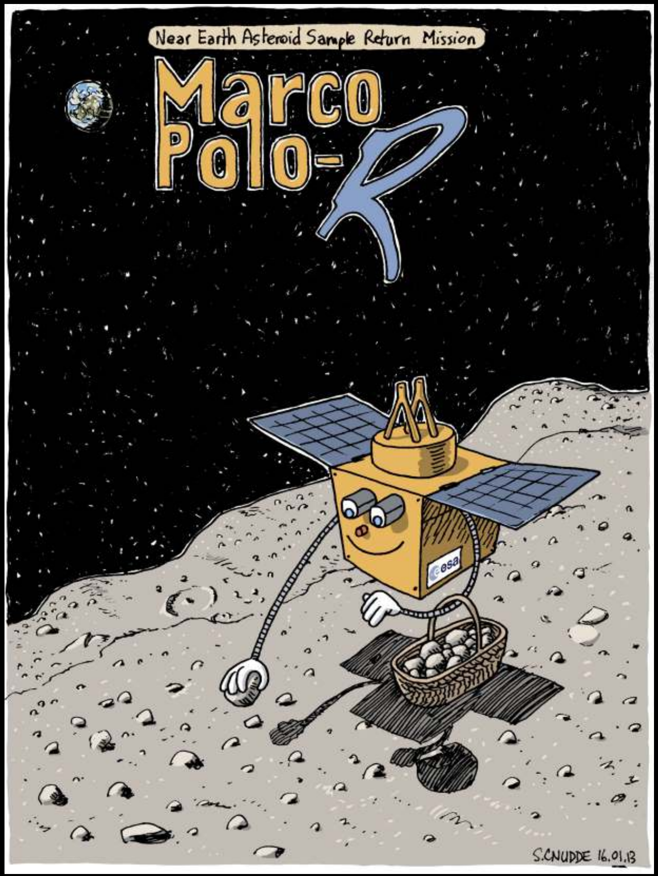
Samples rapidly transferred to a curation facility

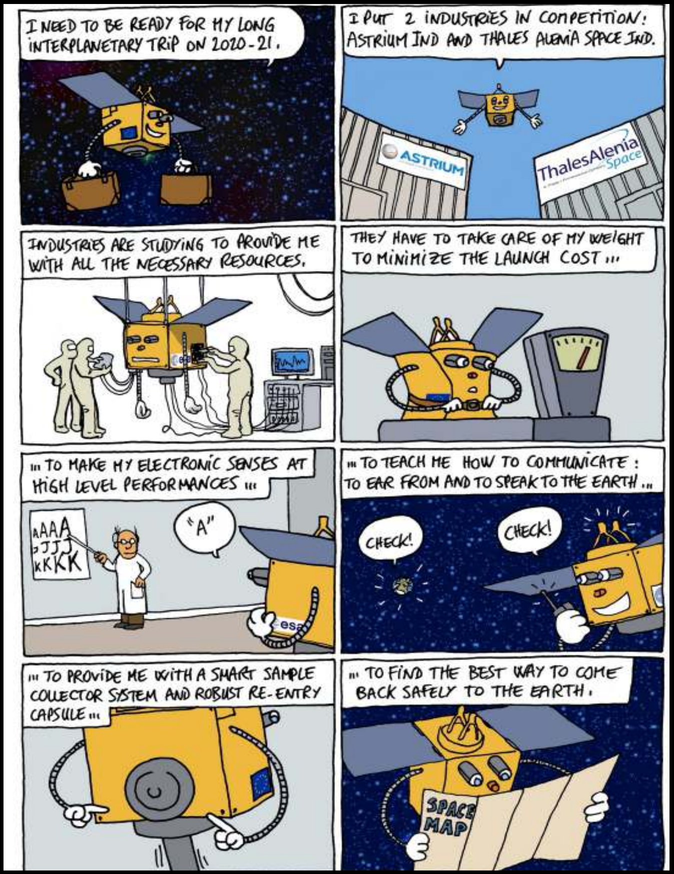
- Canister opened in ultraclean environment
- Preliminary examination phase by a selected team
- Distribution to the community at large – Independent allocation committee
- Archiving for future generations



JAXA Curation Facility
Cost ~10 Millions $US

Asteroid sample return missions generate a tremendous public interest



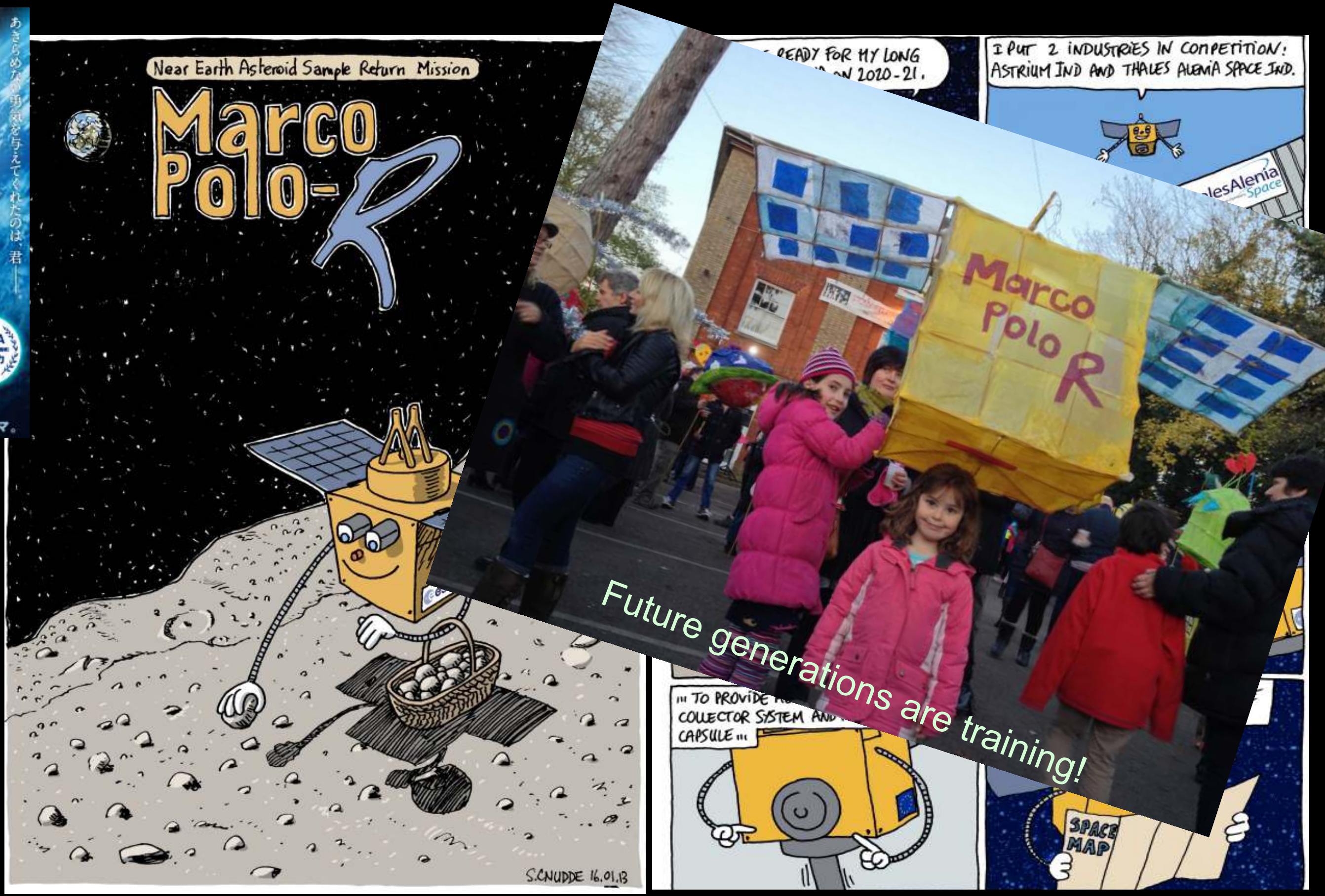


MarcoPolo-R is on Facebook

MarcoPolo-R comics book

Translations in English, French, German, Italian, Spanish, Portuguese, Greek, Russian, Chinese

Asteroid sample return missions generate a tremendous public interest



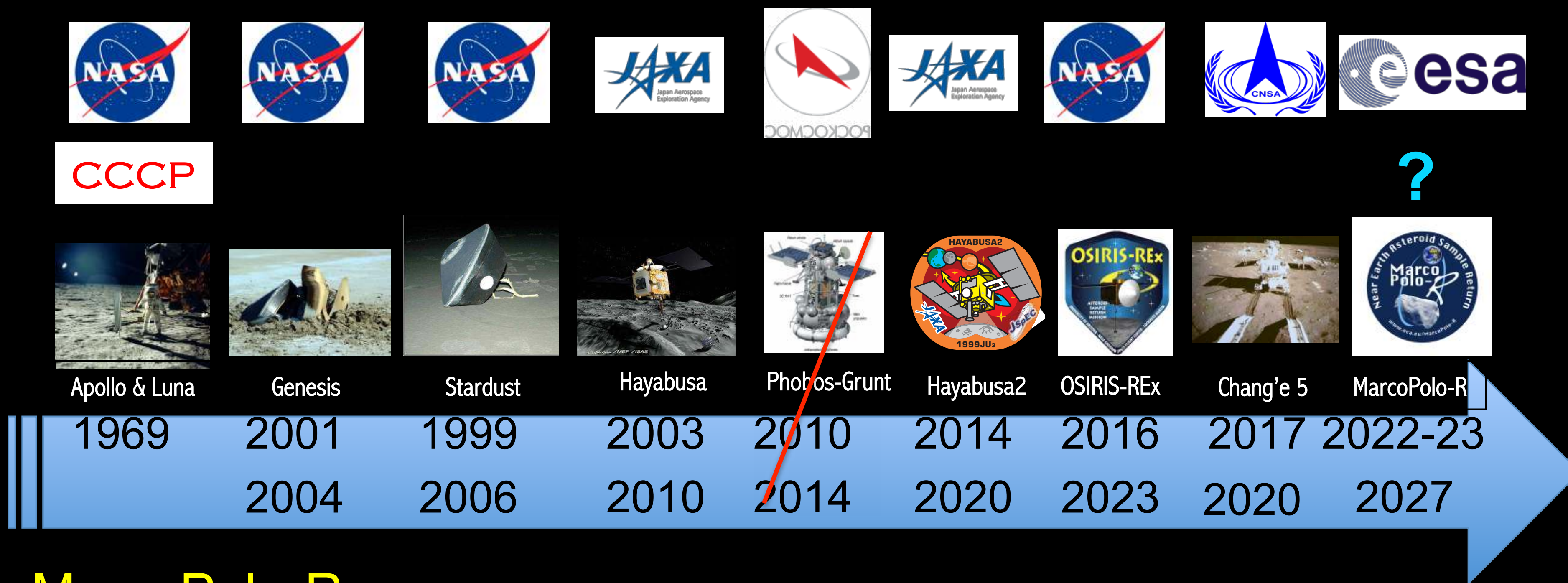
A pacifier for future scientists! (found on internet)

MarcoPolo-R is on Facebook

MarcoPolo-R comics book

Translations in English, French, German, Italian, Spanish, Portuguese, Greek, Russian, Chinese

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