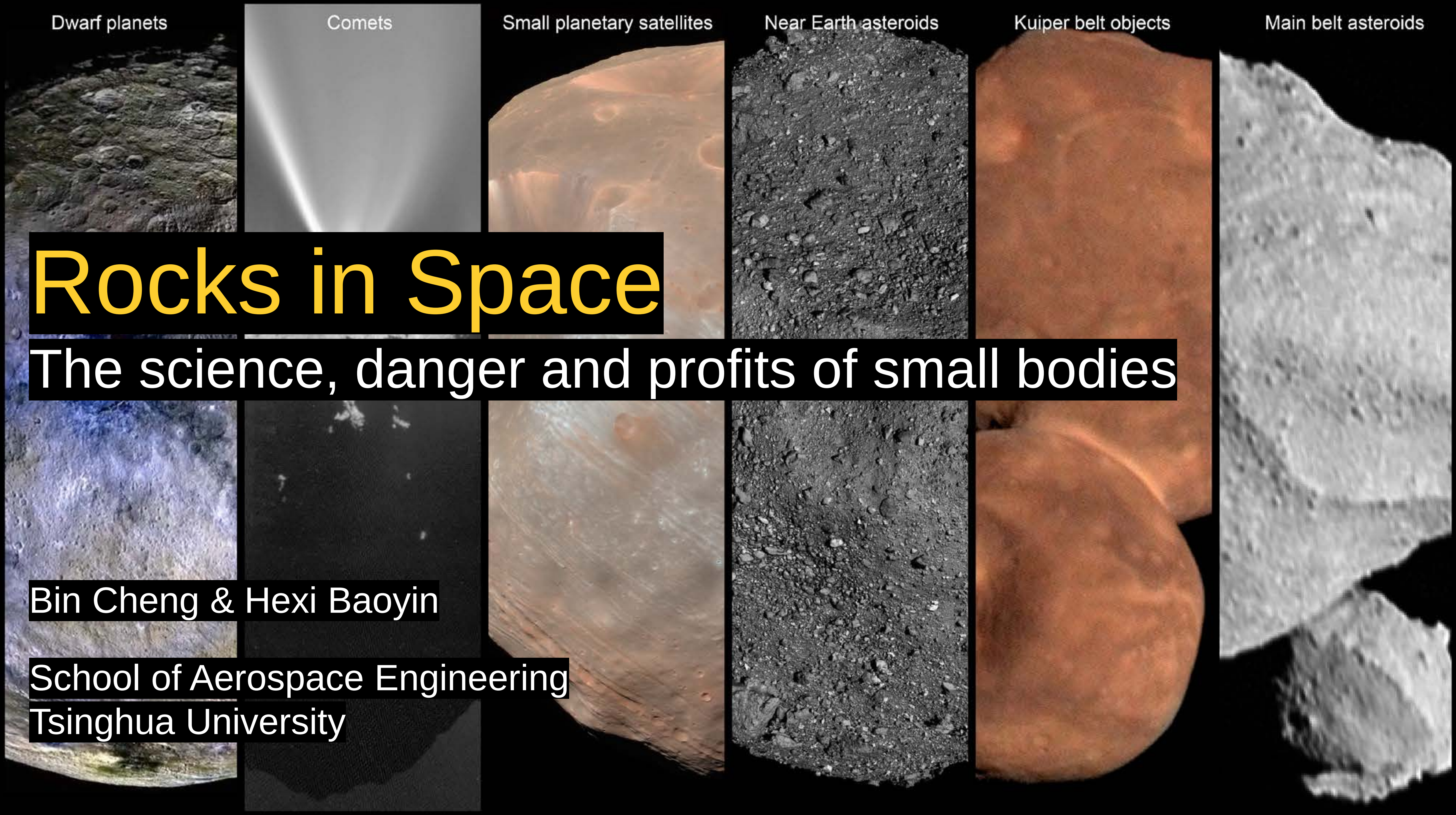


Rocks in Space

The science, danger and profits of small bodies

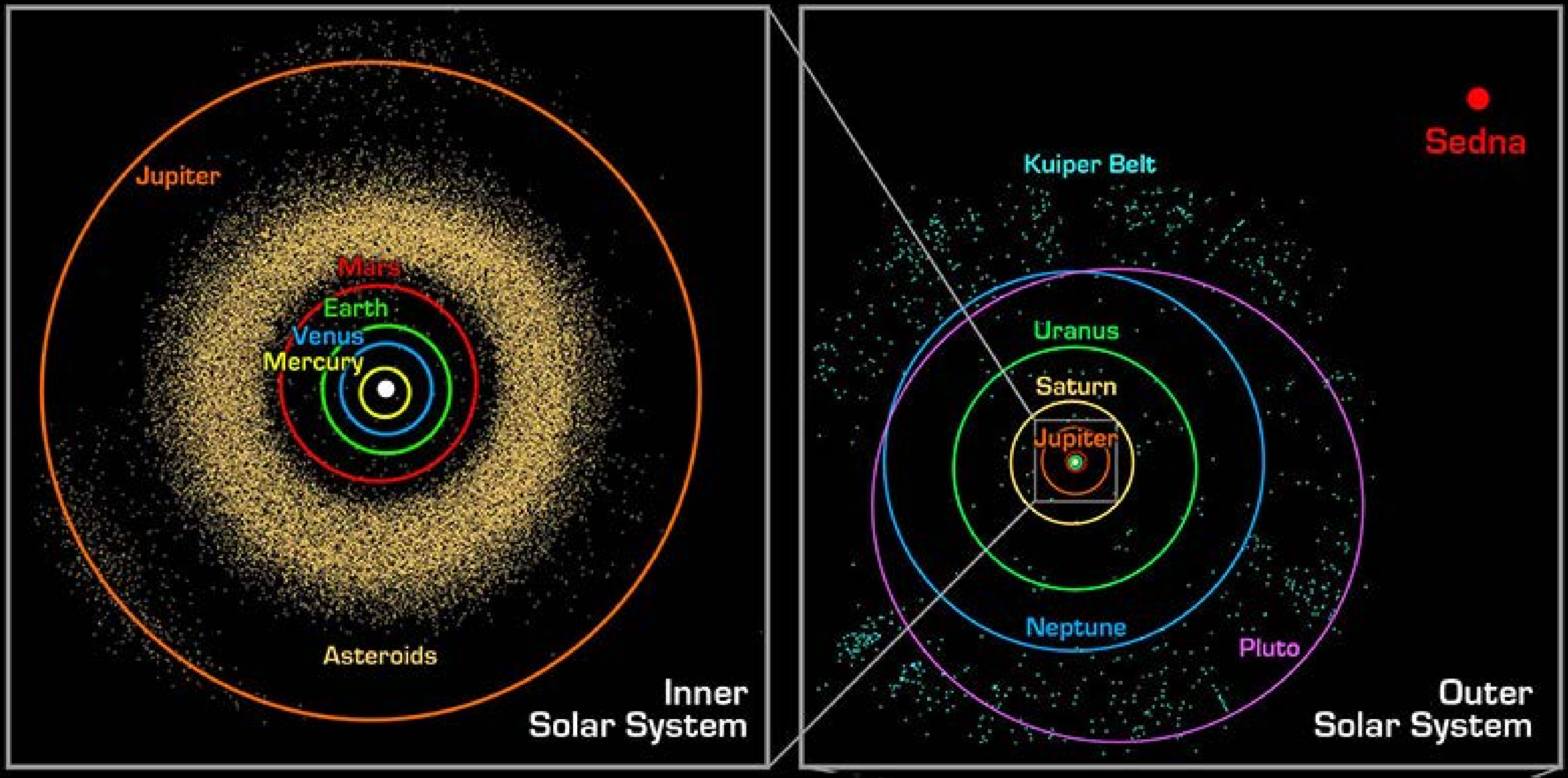
Bin Cheng & Hexi Baoyin

School of Aerospace Engineering
Tsinghua University

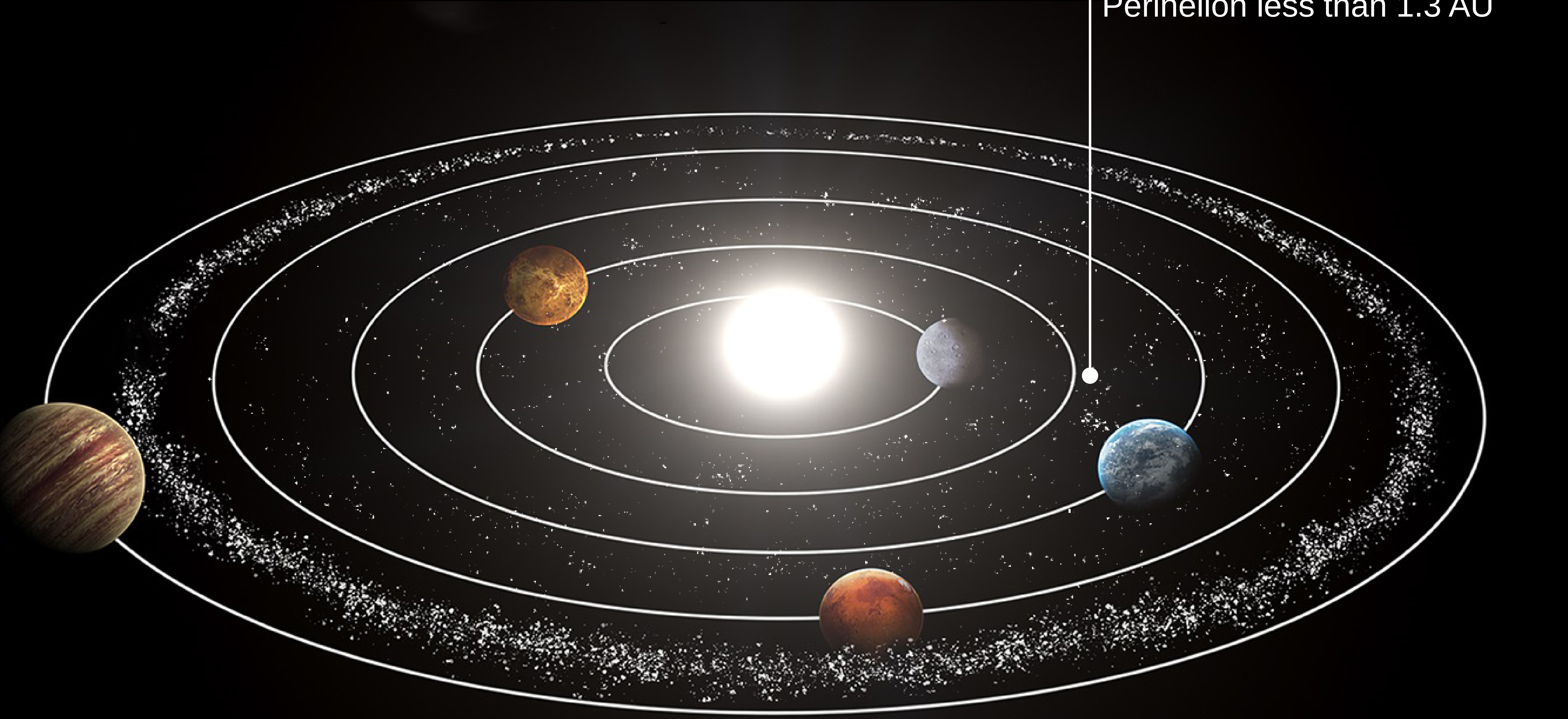
What are small bodies?

Small solar system bodies

- Asteroids, comets, the objects in the Kuiper Belt and the Oort cloud, small planetary satellites, interplanetary dust and so on.
- Largest one is Ceres (a dwarf planet), almost 1000 km across.
- Smallest is … as tiny as grains of sand.
- Diverse collection of bodies with differing compositions, shapes, sizes, history, locations…



SMALL OBJECTS IN THE SOLAR SYSTEM



1 AU = Earth-Sun distance ~150 million km

This infographic is representative and not to scale.

esa

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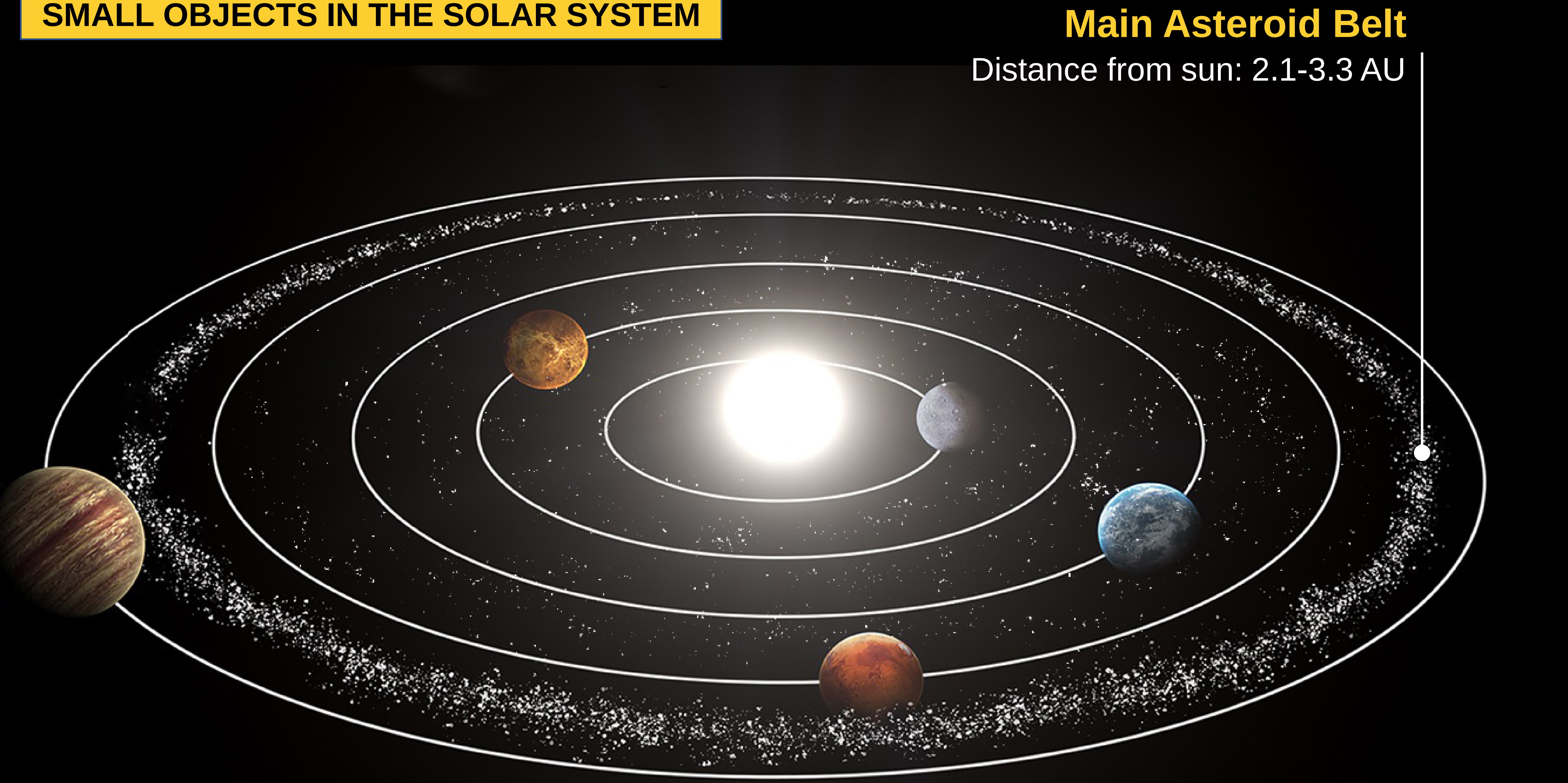

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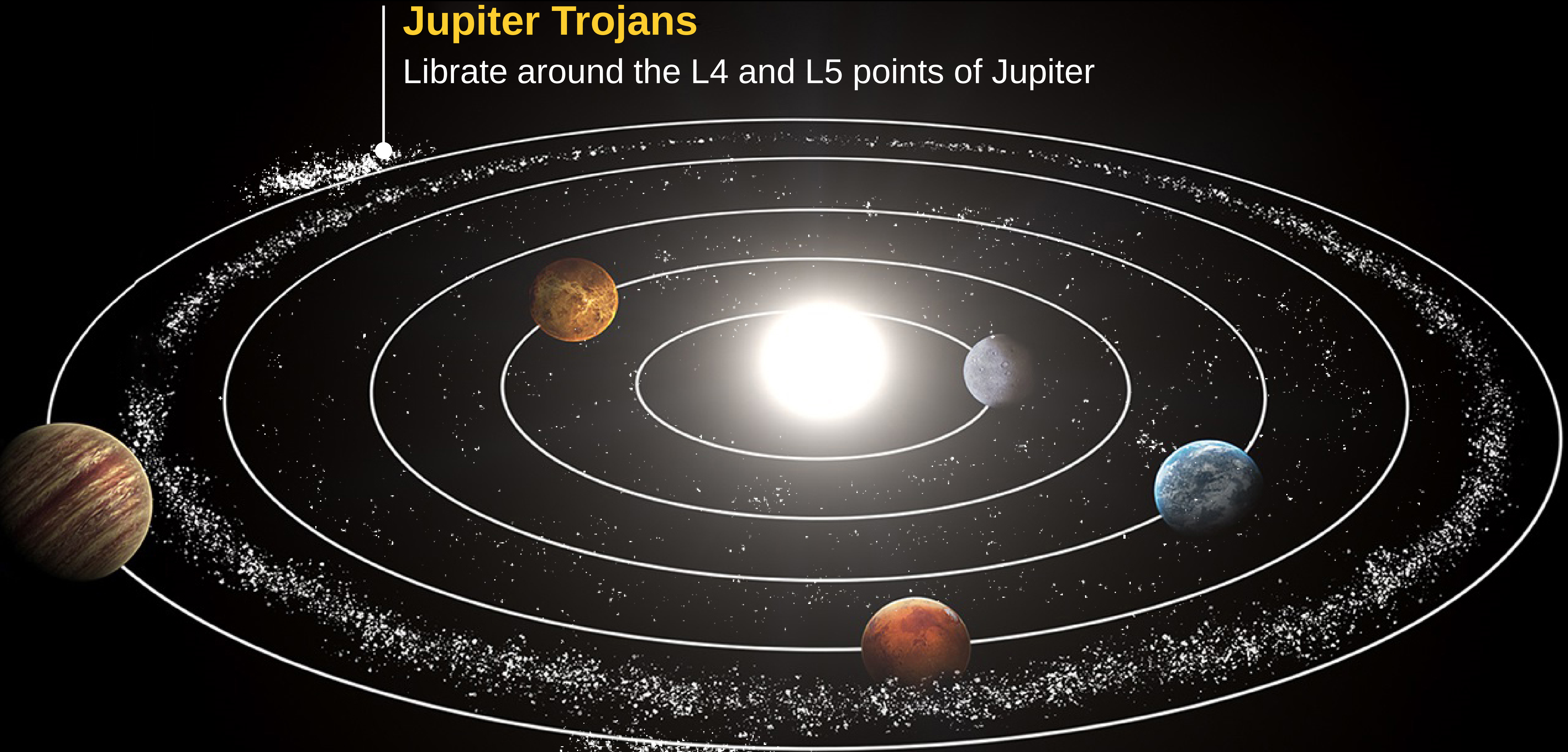

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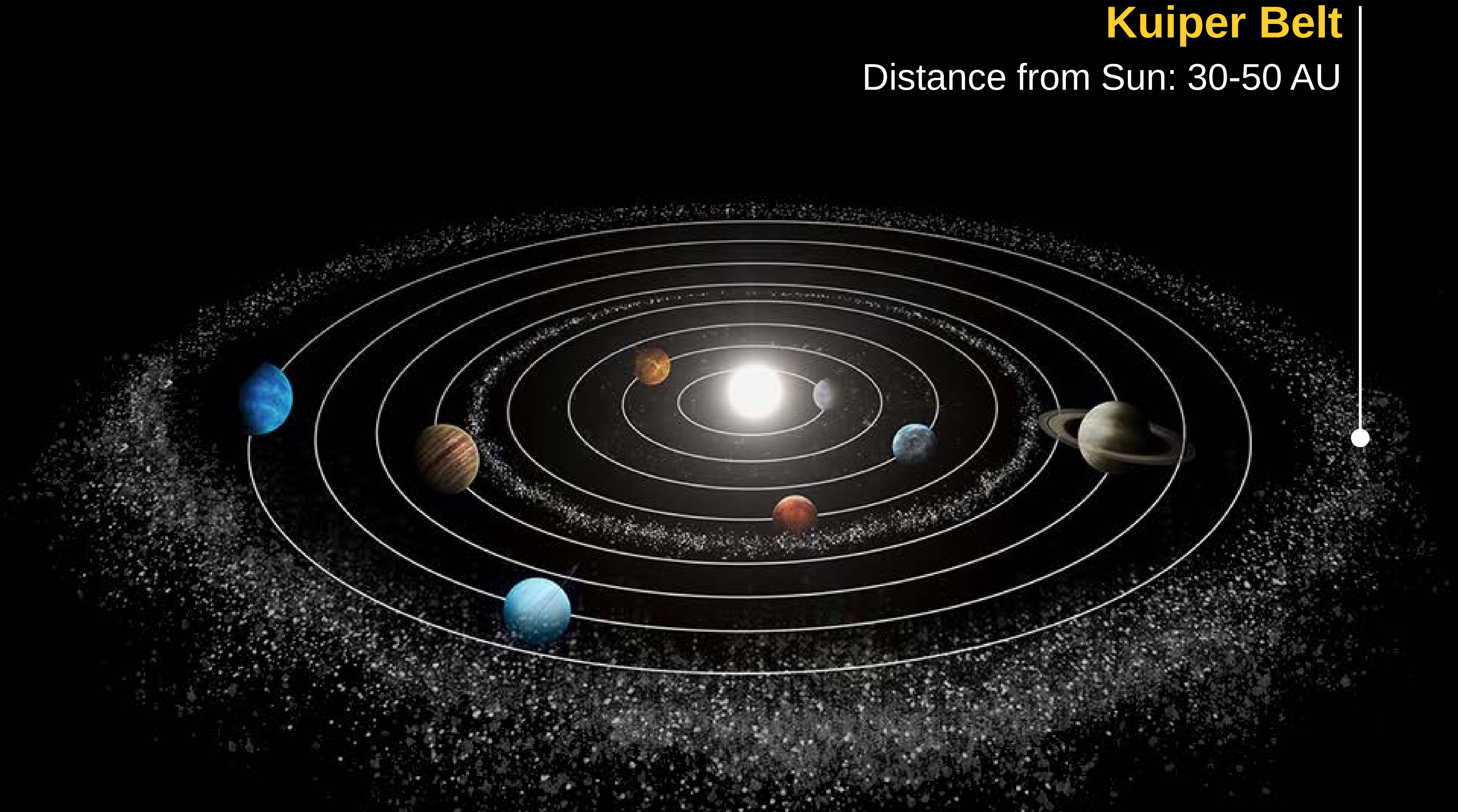

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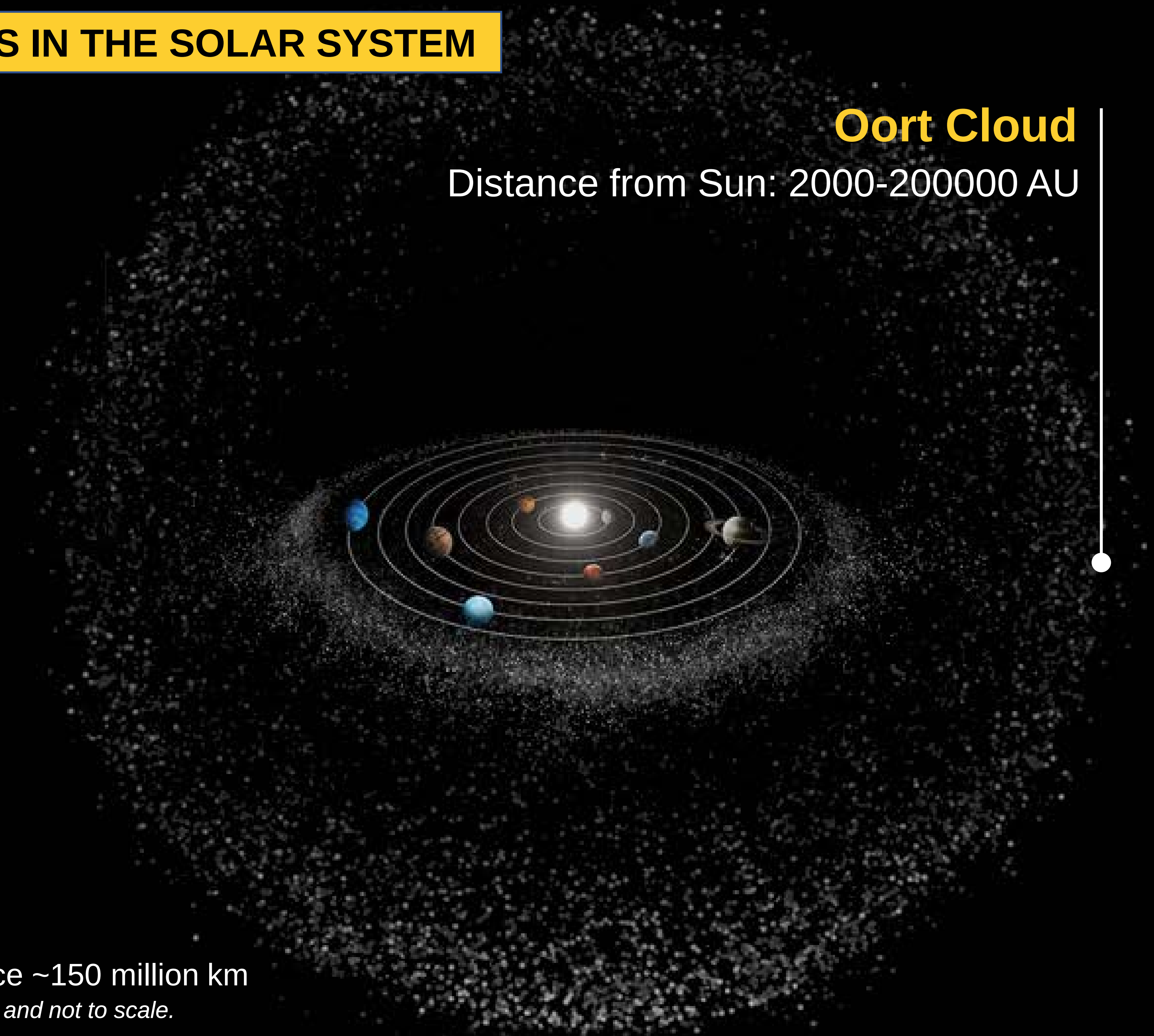
SMALL OBJECTS IN THE SOLAR SYSTEM

Oort Cloud

Distance from Sun: 2000-200000 AU



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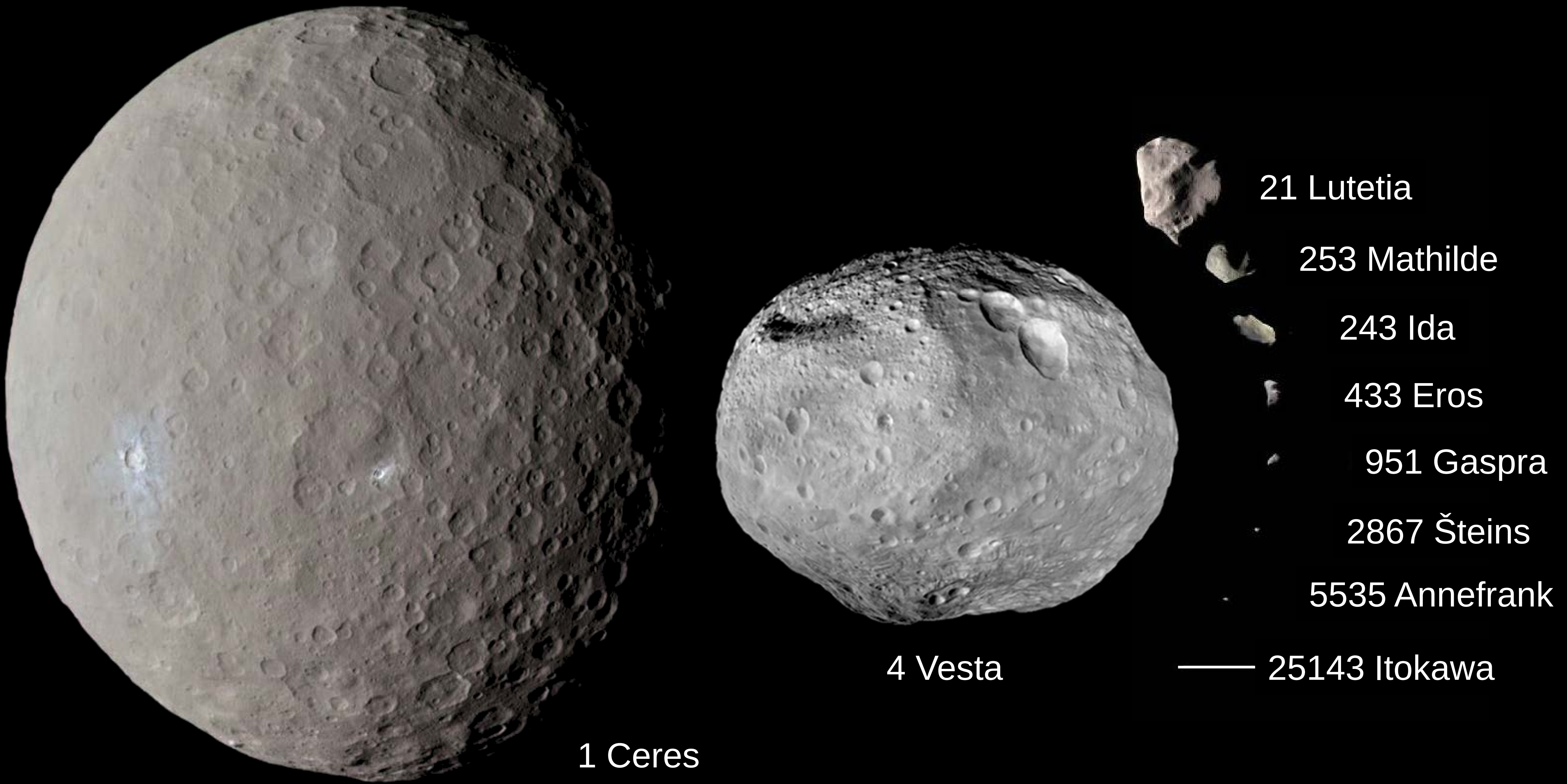
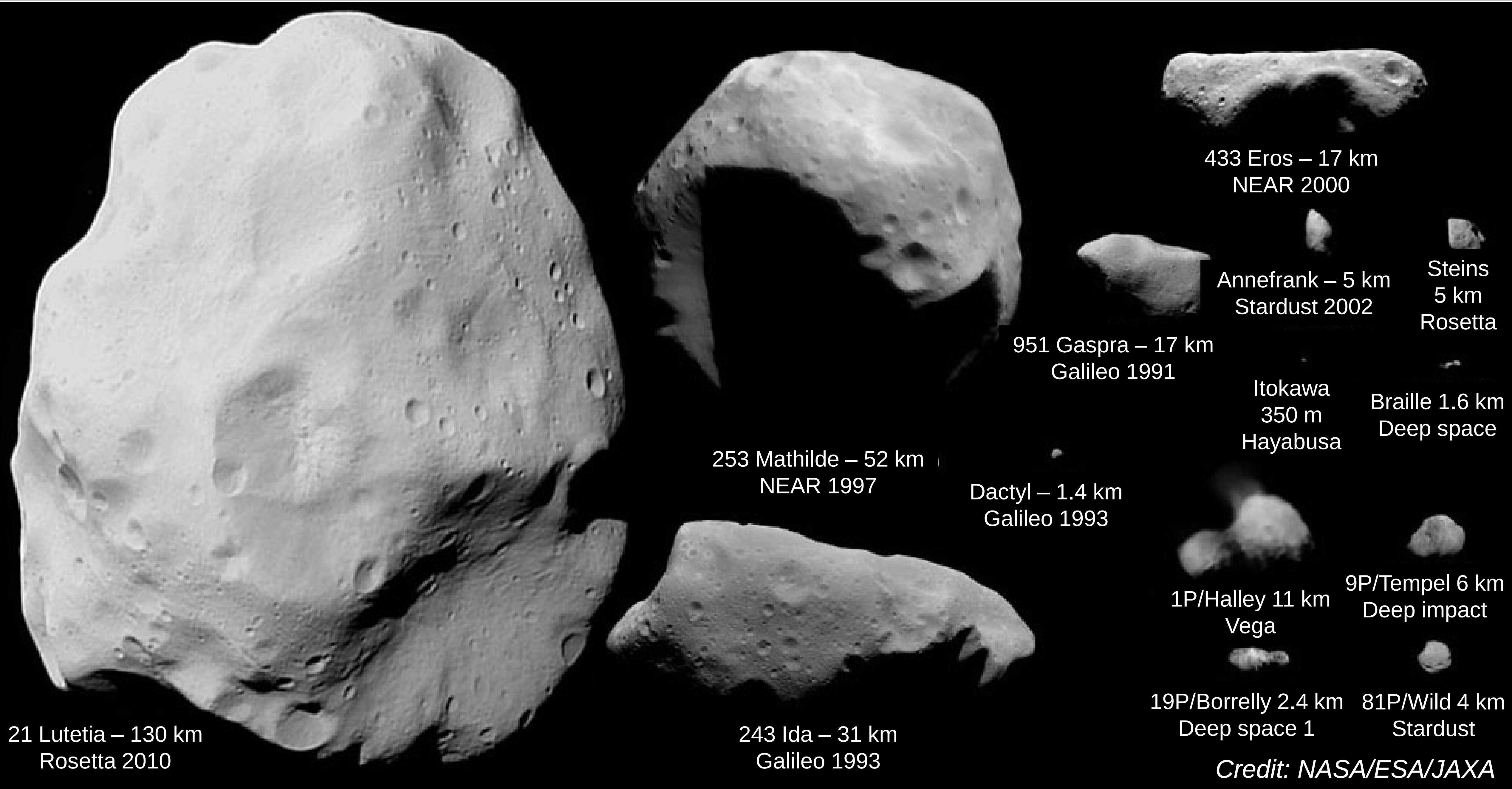
Small but diverse worlds

Small but diverse worlds



Credit: NASA/JPL

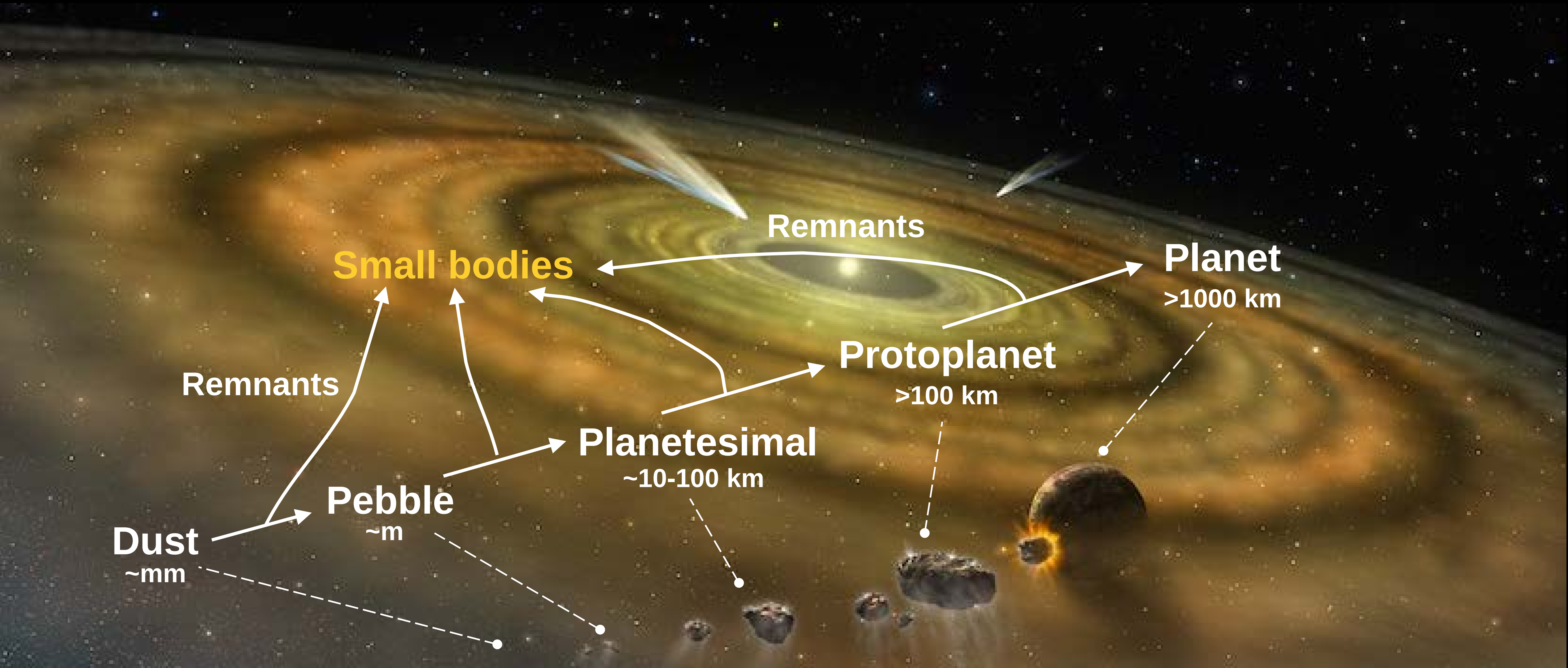
Small but diverse worlds

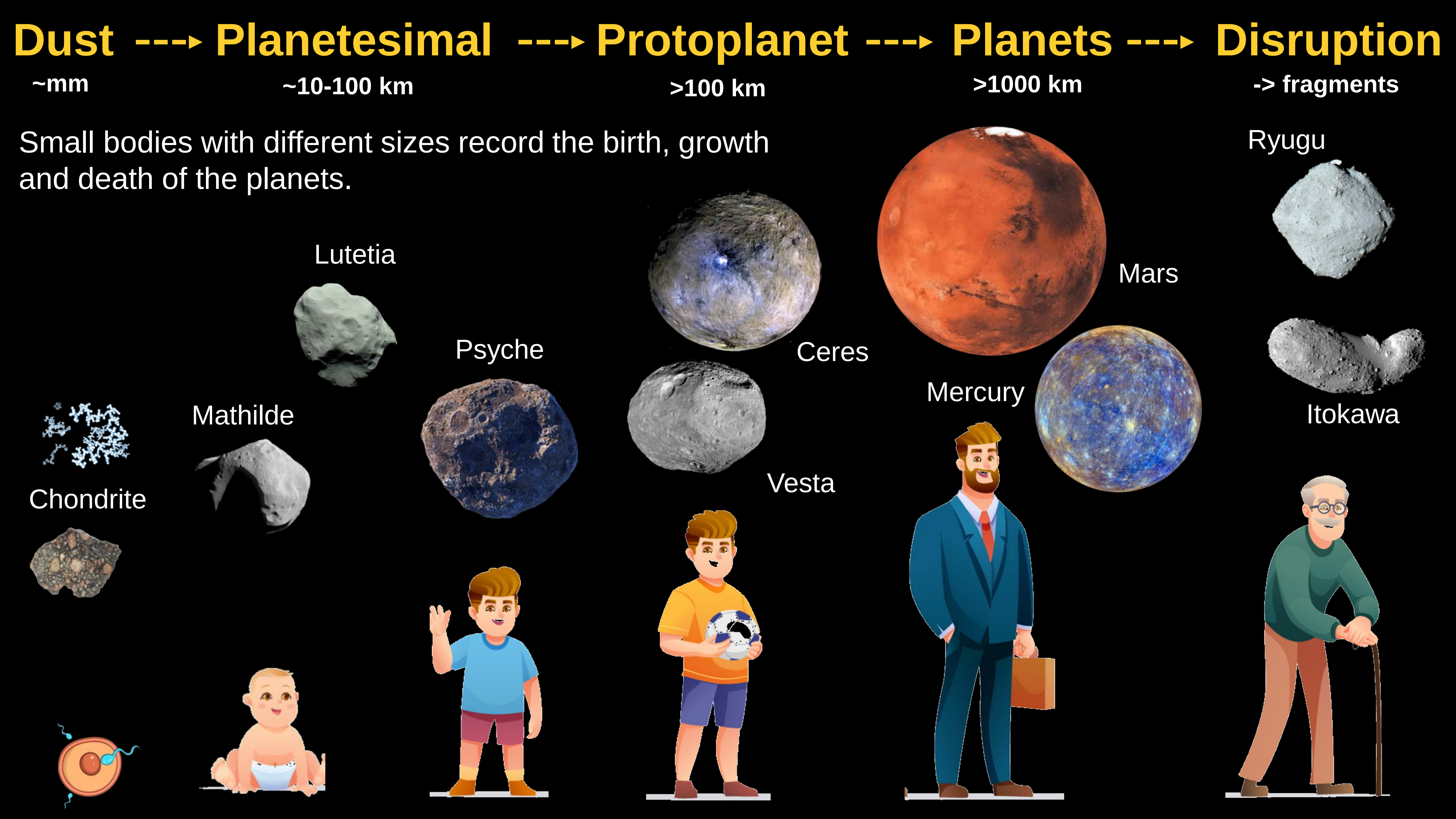


Why are we interested?

Why are we interested?

- **Time capsules from the early solar system**
  - “Leftovers” that record the birth, growth and death of the planets.

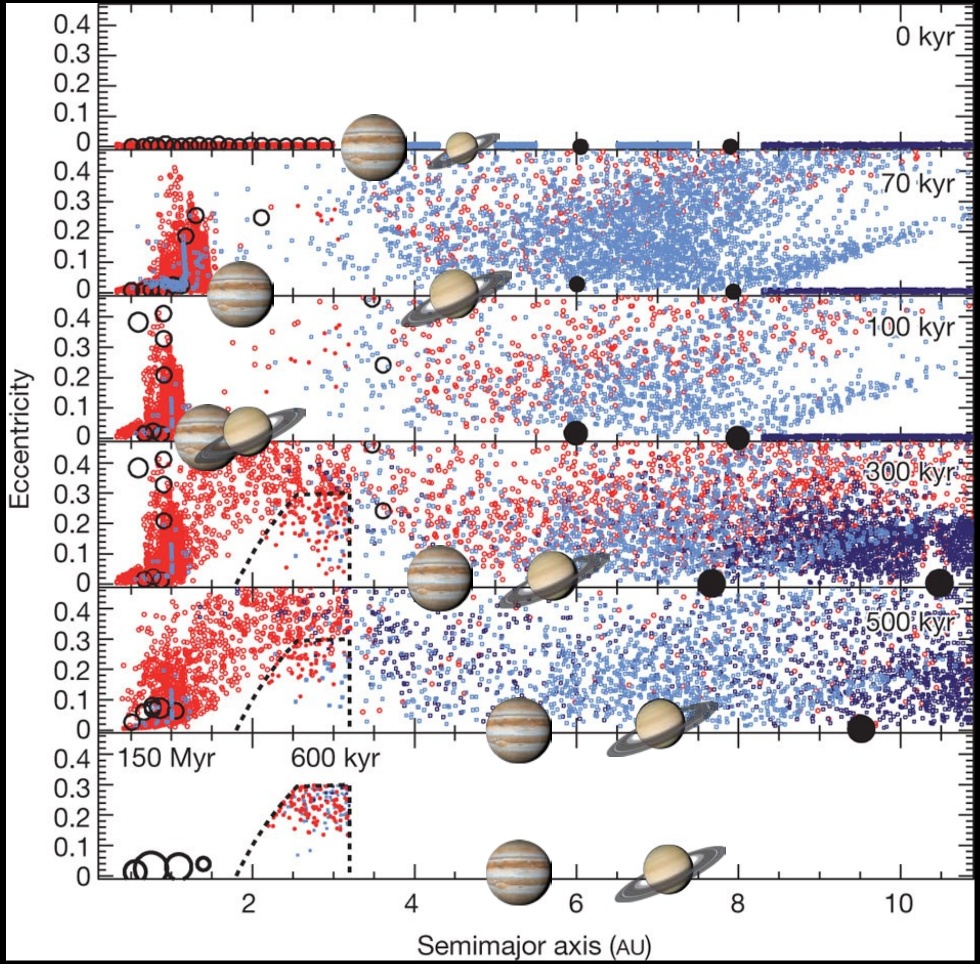



Dust ---> Planetesimal ---> Protoplanet ---> Planets ---> Disruption
~mm
~10-100 km
>100 km
>1000 km
-> fragments
Small bodies with different sizes record the birth, growth and death of the planets.
Ryugu
Lutetia
Mars
Psyche
Ceres
Mercury
Itokawa
Mathilde
Vesta
Chondrite

Why are we interested?

Time capsules from the early solar system

- "Leftovers" that record the birth, growth and death of the planets.
- "Tracer particles" that record how the major planets move over time.



Migration of Jupiter and Saturn (Walsh et al *Nature* 2011)

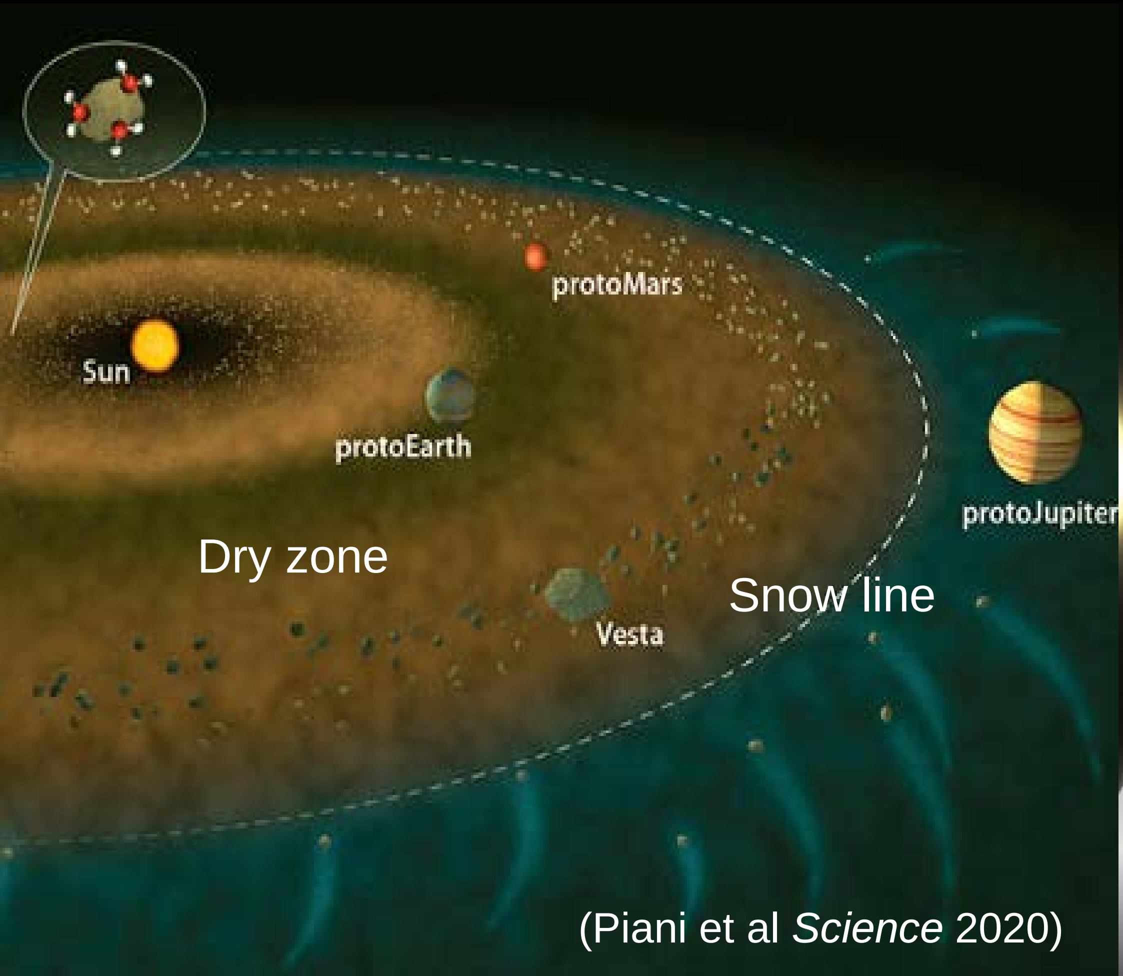
Quite similar with ⇨

Fluid dynamics experiment

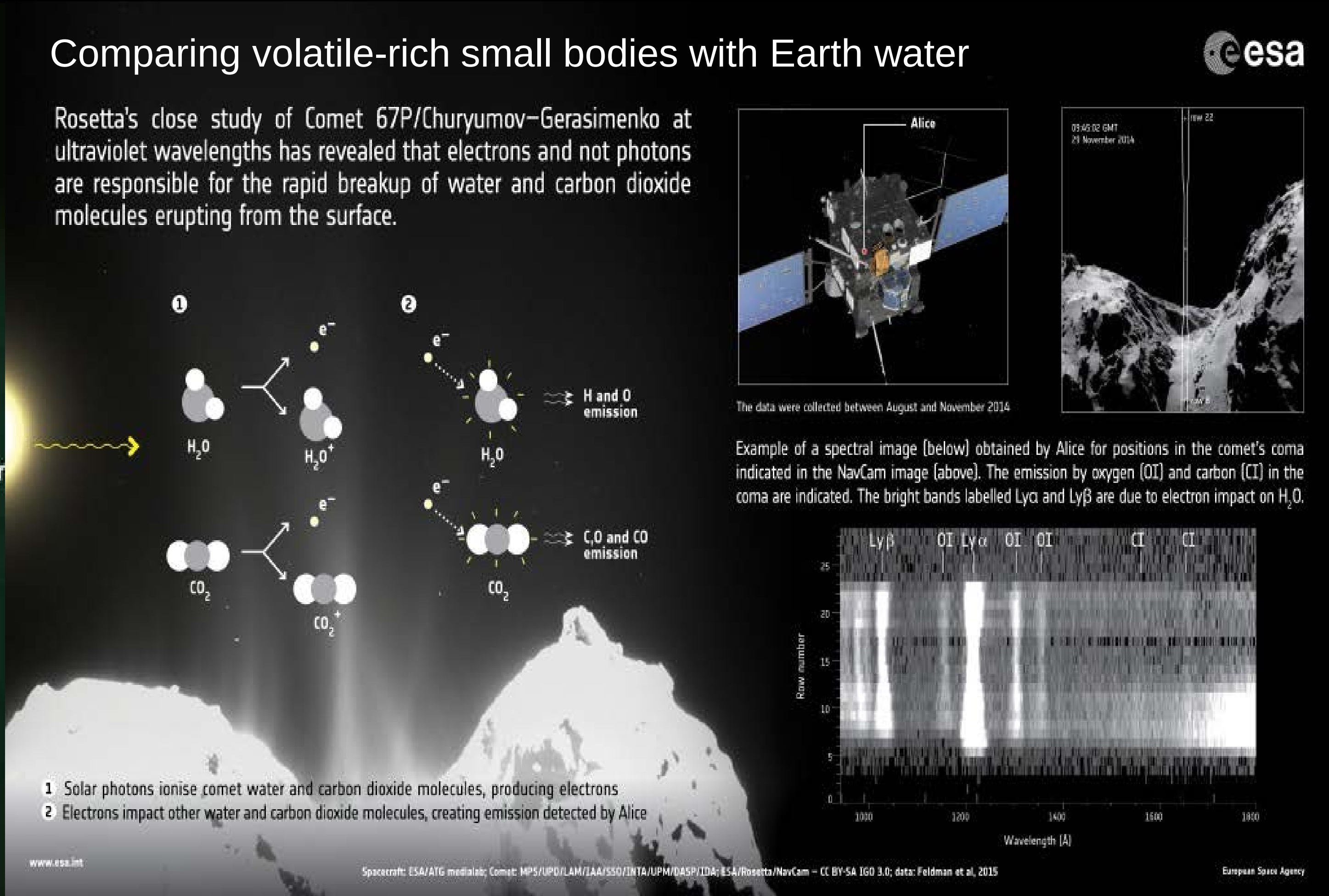
Why are we interested?

■ They have shaped life on Earth

- "Life-starters" that seed water and organic compounds to ancient Earth.



(Piani et al *Science* 2020)



Why are we interested?

They have shaped life on Earth

- “Life-starters” that seed water and organic compound to ancient Earth.
- “Life-enders” that caused extinction event 66 Mya, and maybe in the future?!

A 10 km size asteroid impacted Earth and ended the age of dinosaurs 66 Mya.

(Hand et al *Science* 2016)

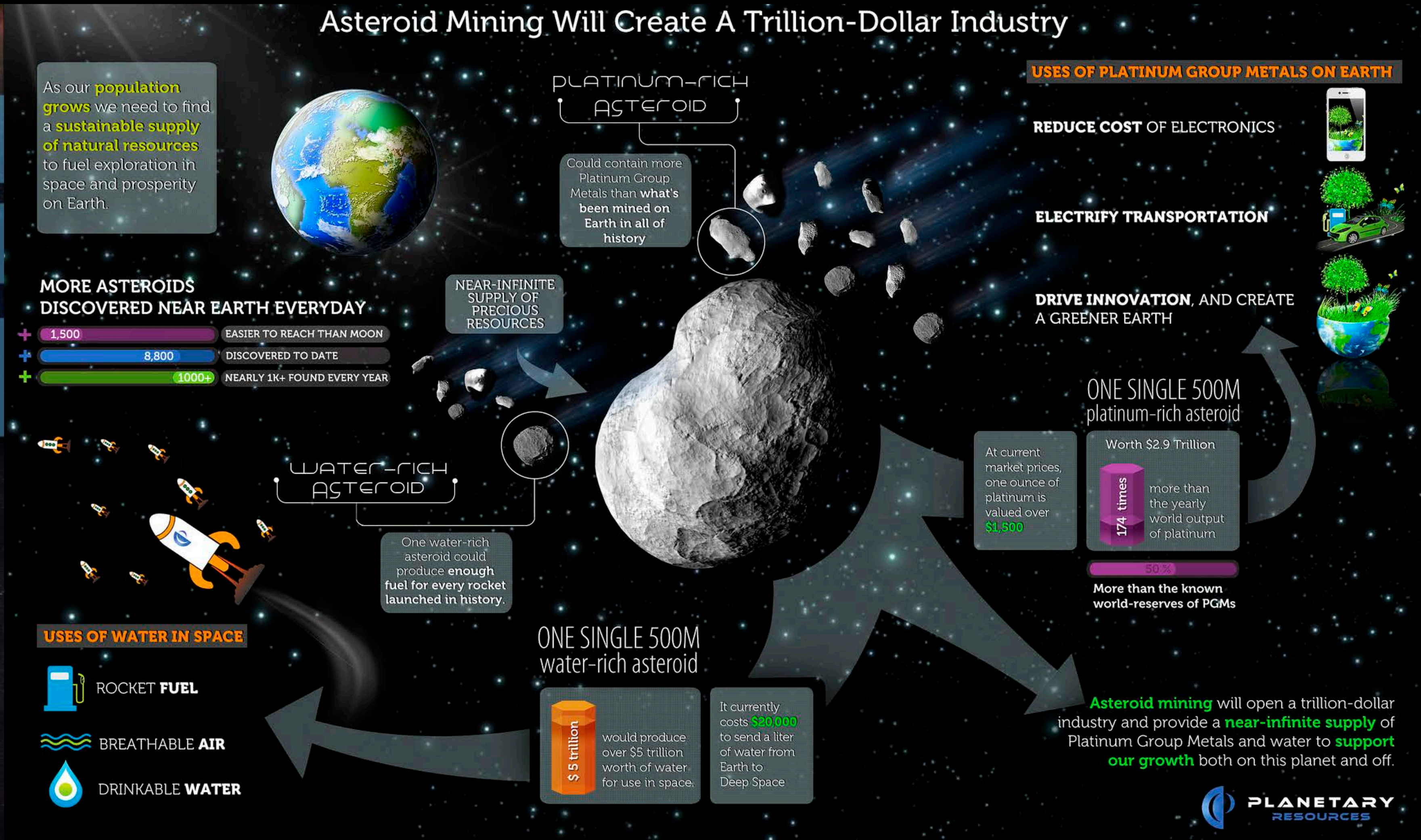
Earth for comparison

Comet Shoemaker-Levy 9 impacted Jupiter in 1994.

What if it had hit our Planet?!

Why are we interested?

- **Asteroid mining: A modern day gold rush**
  - Sound like Sci-Fi for years… but has recently spawned new interest.



What small body missions have we done?

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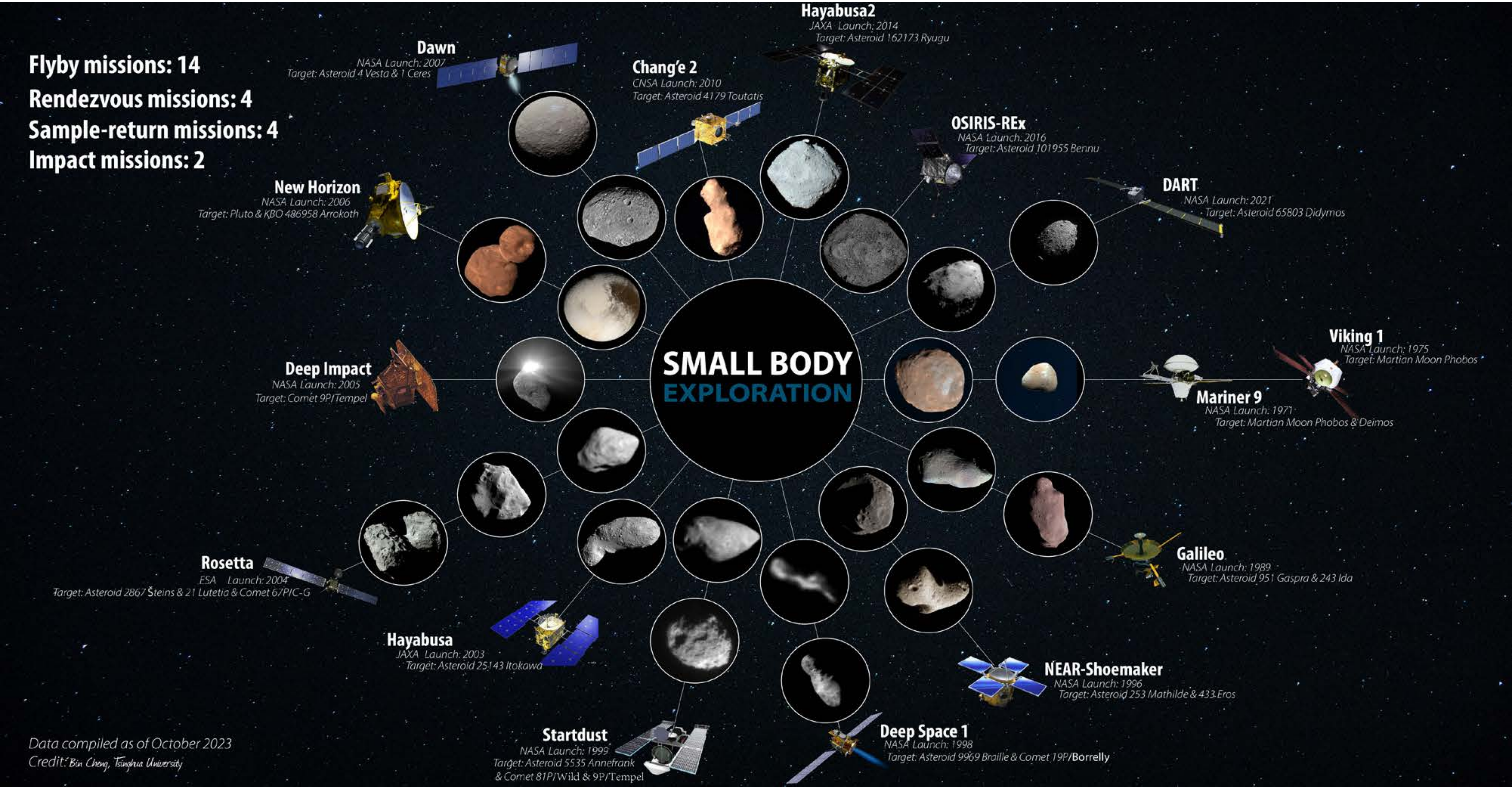

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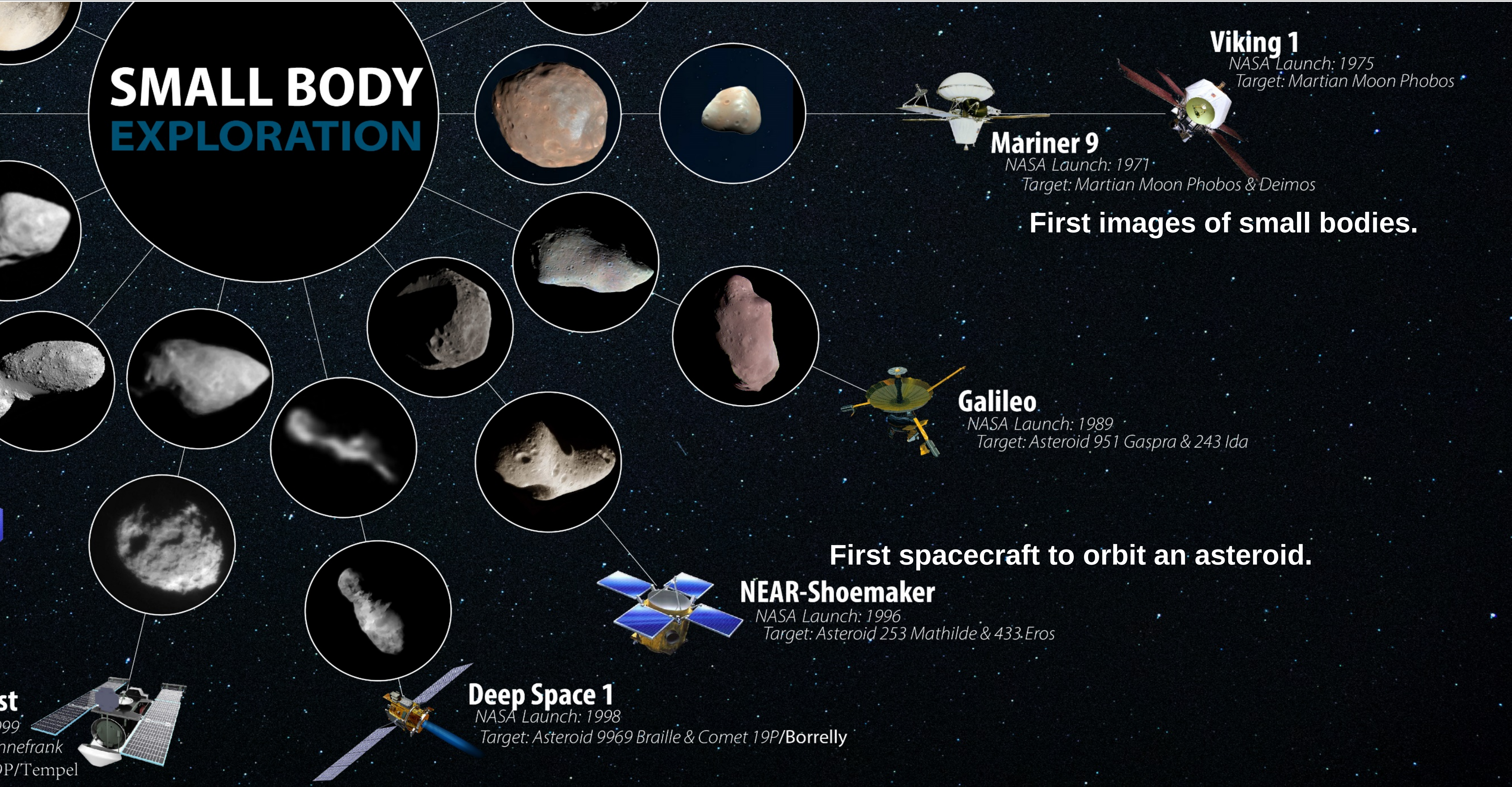
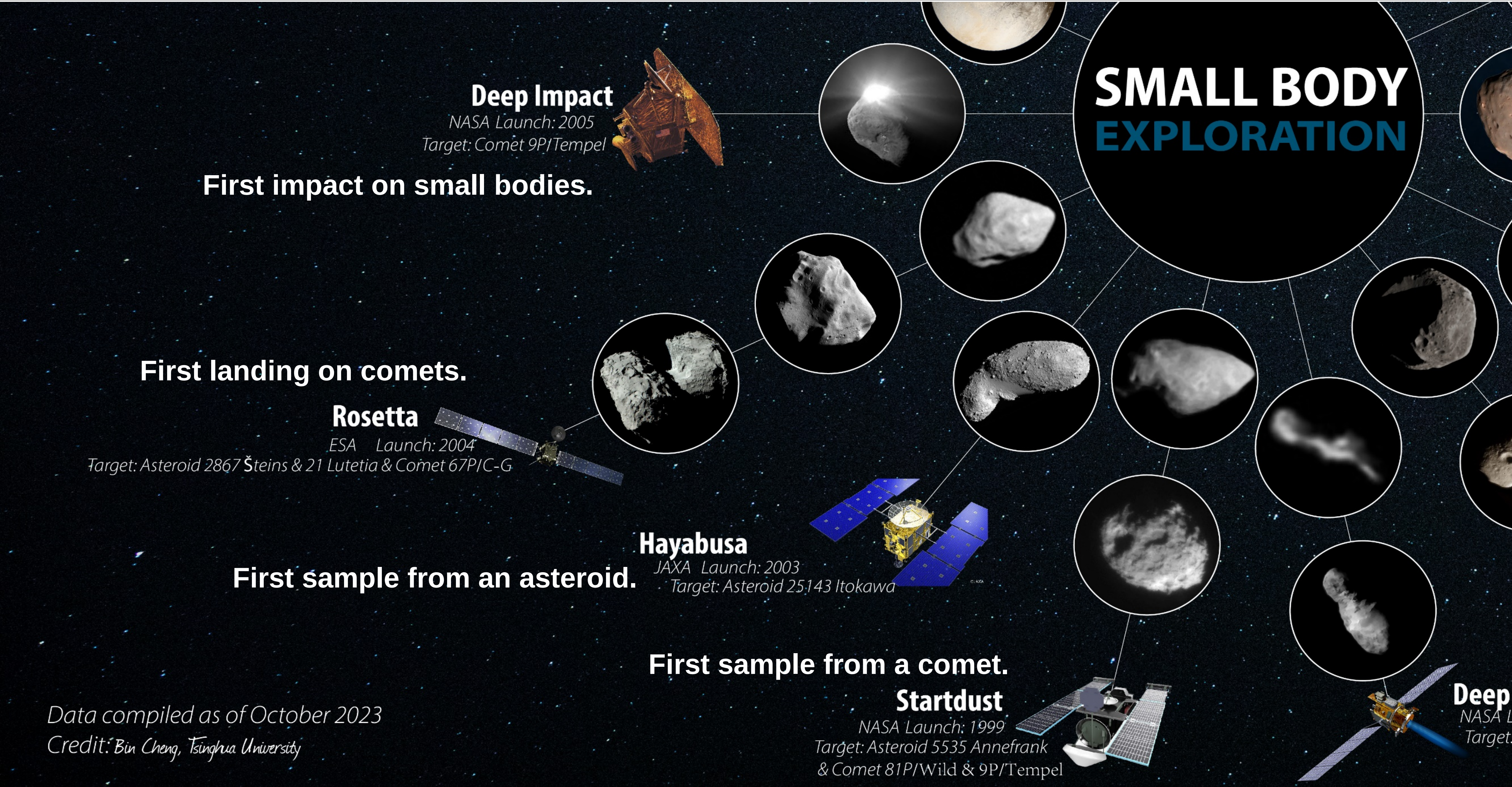


First images of small bodies.

First spacecraft to orbit an asteroid.

What small body missions have we done?



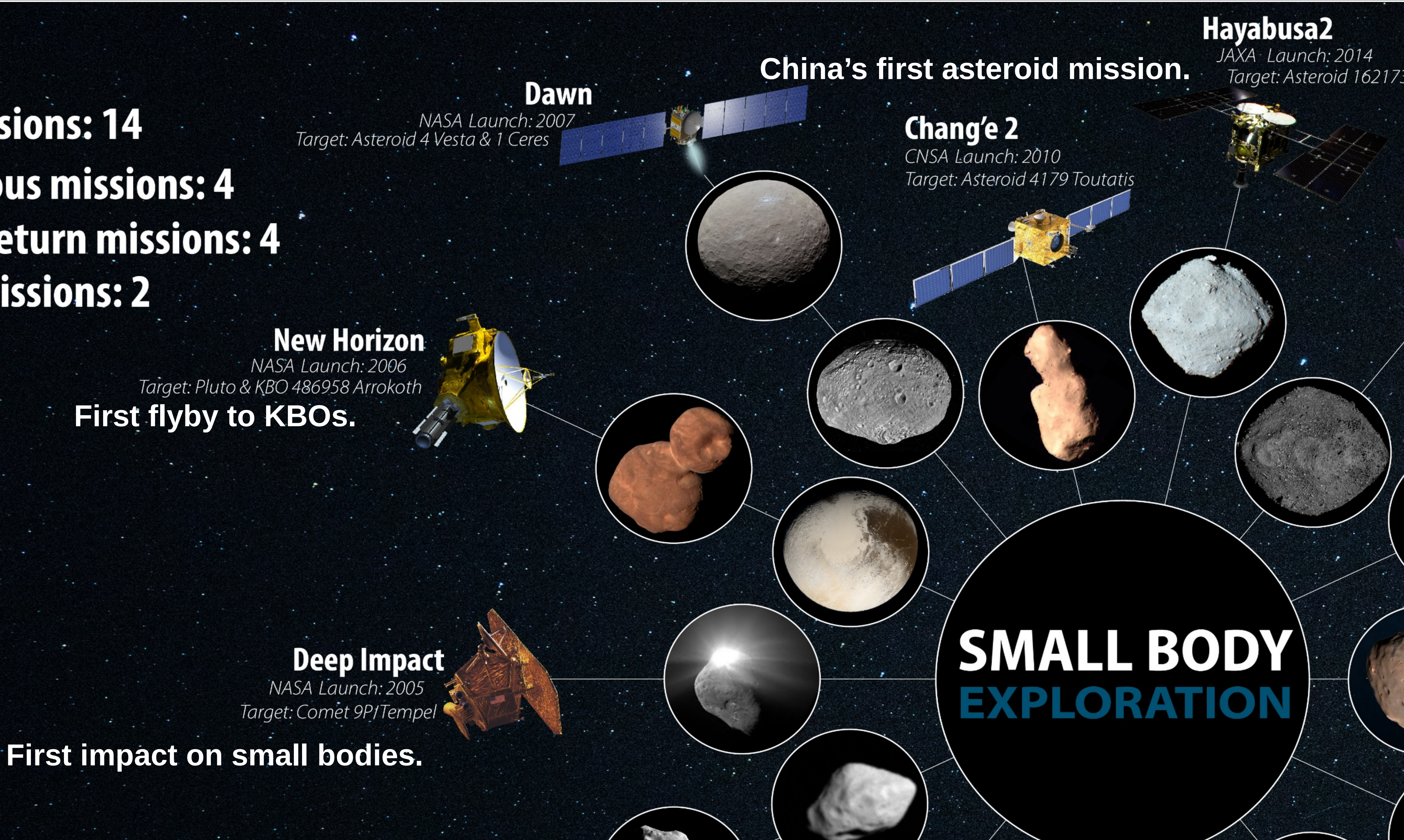
What small body missions have we done?

Flyby missions: 14

Rendezvous missions: 4

Sample-return missions: 4

Impact missions: 2



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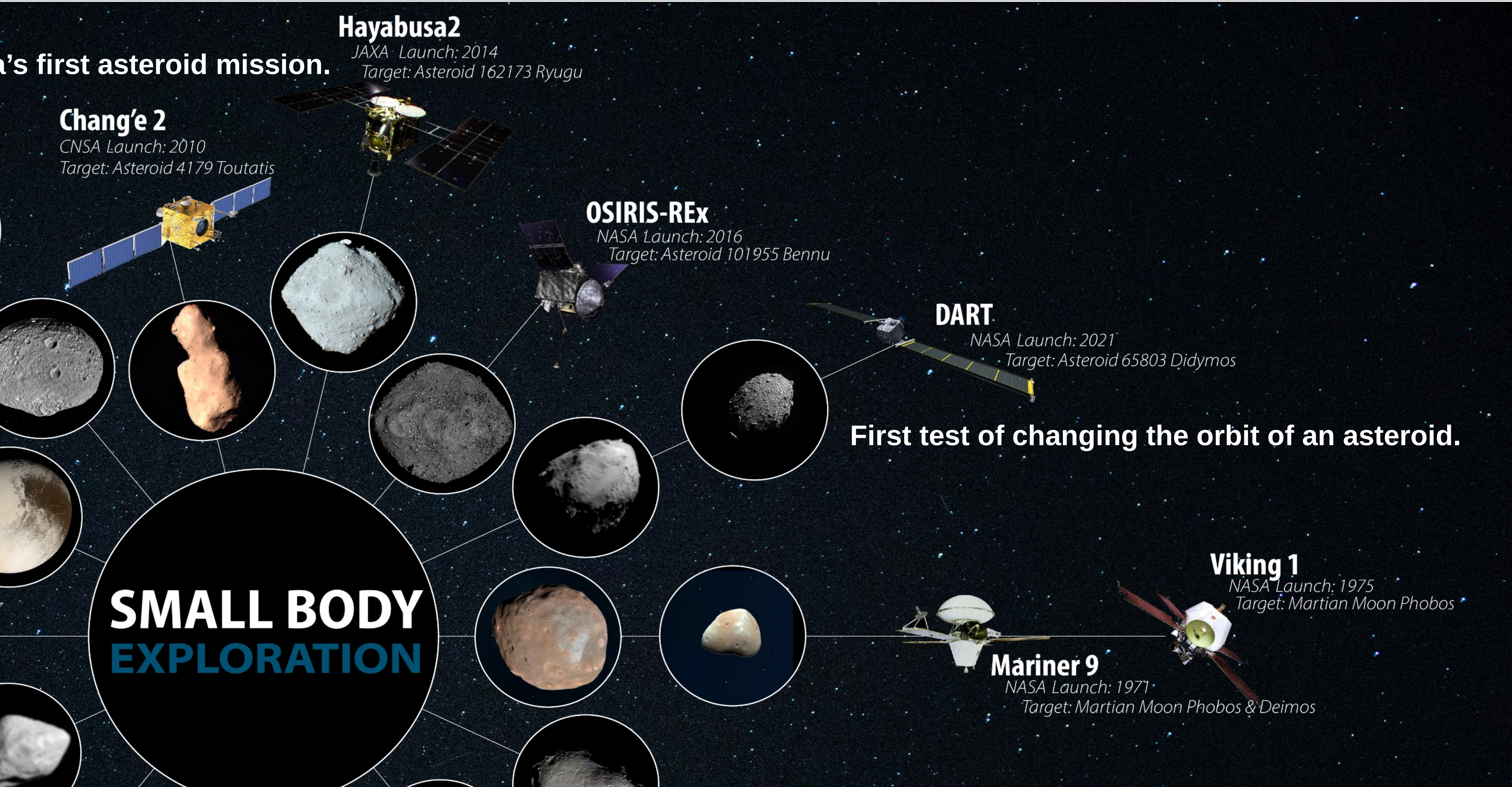

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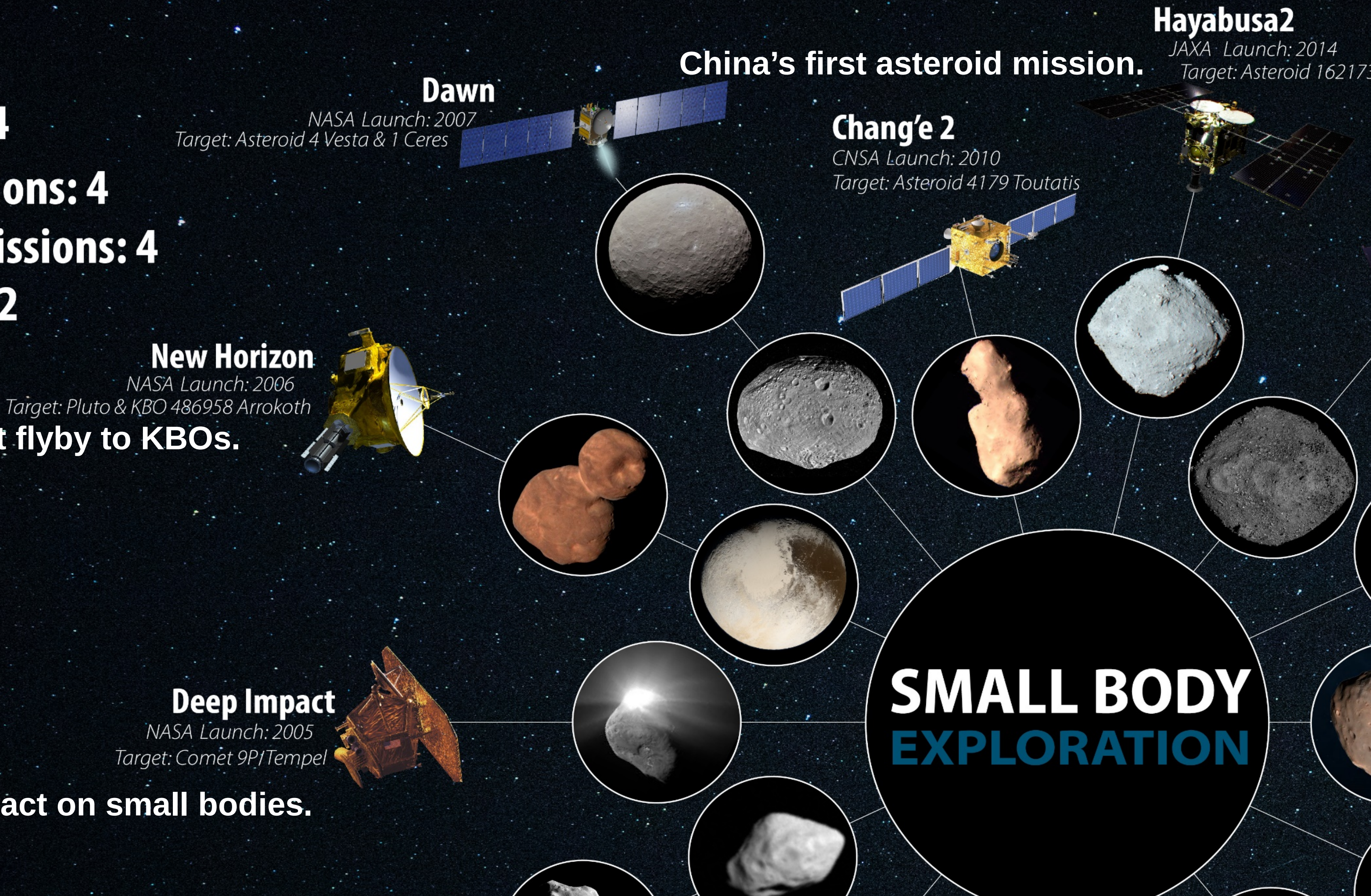


China's first asteroid mission.

First flyby to KBOs.

First impact on small bodies.

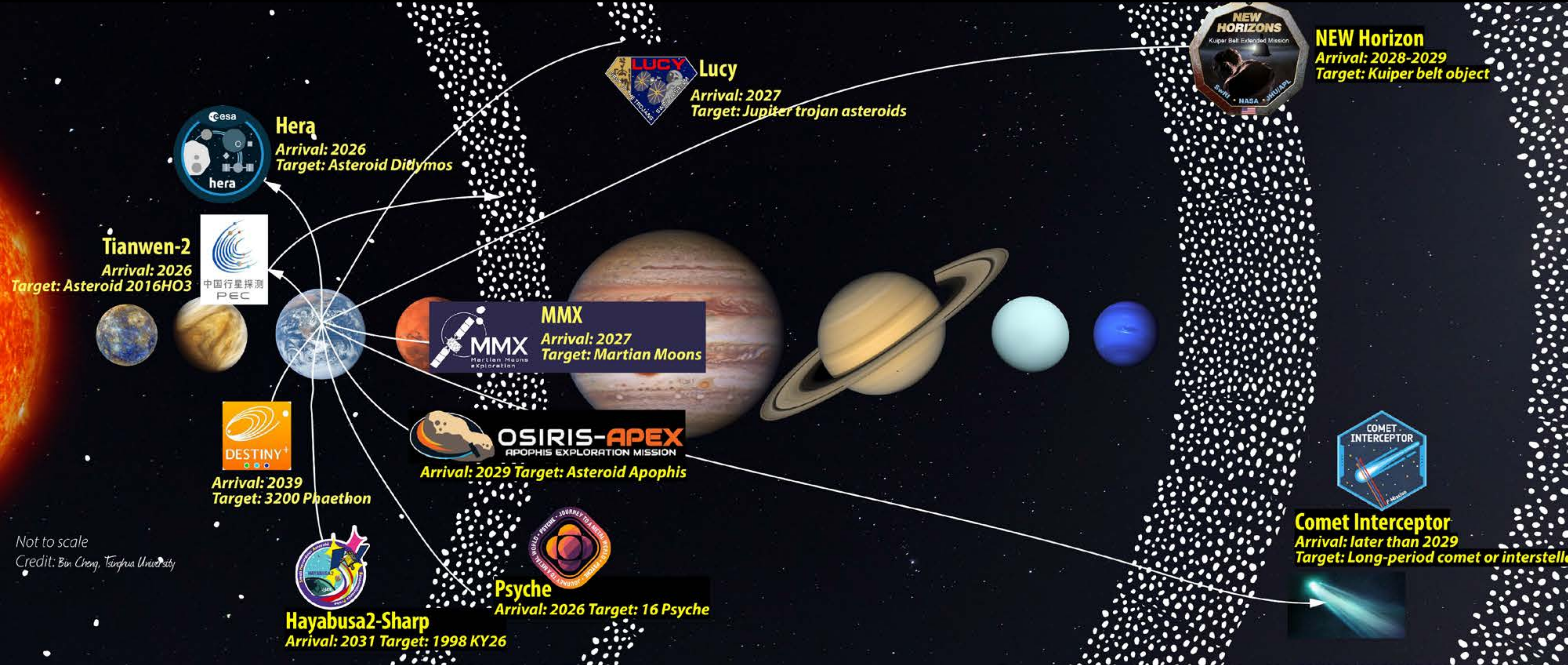
What about the future?

What about the future?

■ Go farther

- At least 10 missions in next 5 years!

Near Earth→Main Asteroid Belt→Jupiter Trojan→Kuiper Belt→Oort cloud



What about the future?

- **Go farther**
  - Near Earth→Main Asteroid Belt→Jupiter Trojan→Kuiper Belt
- **Diverse targets**
  - Asteroid C-type√ S-type√ M-type× (NASA’s Psyche mission)
  - Short-period comets√ Long-period comets× Interstellar Object× (ESA’s Comet Interceptor mission)
  - Martian Moons× (JAXA’s MMX mission)
  - KBOs√
  - Size: 100 m – 100 km√ <100 m×(most dangerous asteroids: China’s Tianwen-2 mission)

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- **Advanced missions**
  - Flyby→Rendezvous→Sample-return→Impact deflection→?
  - Manipulate asteroid trajectories (for mining or planetary defense)?
  - In-Situ Resource Utilization?

What about the future?

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Advanced missions

- Flyby→Rendezvous→Sample-return→Impact deflection→?
- Manipulate asteroid trajectories (for mining or planetary defense)?
- In-Situ Resource Utilization?

More material back to Earth

- Stardust: 1 mg (1999) → Hayabusa: <1 g (2003) → Hayabusa2: 5.4 g (2014) → OSIRIS-REx: ~249 g (2016) → ?
- Still far from the scale required for asteroid mining… How to significantly increase it?

Rocks in Space: The Science, Danger and profits of small bodies

- We are living in a “golden age” of small body exploration!
- For science, for Human beings, and … for Money!

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