Exemplary talk: Special Topics in Observational Astrophysics, 2018/09/21

Asteroid Sample-Return Missions: OSIRIS-REx and Hayabusa 2

Xuening Bai (白雪宁)

Institute for Advanced Study (Tsinghua)

& Tsinghua Center for Astrophysics

清華大學

Tsinghua University

Outline

- Basic Facts: OSIRIS-REx and Hayabusa 2
- Scientific background
  - Basic properties of asteroids and meteorites
  - Previous sample return missions
- Mission objectives/profile: ORISIS-REx
- Mission objectives/profile: Hayabusa 2
- Summary

What is OSIRIS-REx?

Origins, **S**pectral **I**nterpretation, **R**esource **I**dentification, **S**ecurity, **R**egolith **Ex**plorer

NASA mission to explore an asteroid, 101955 Bennu, under the New Frontiers program (after Juno/New Horizons).

Mission timeline:

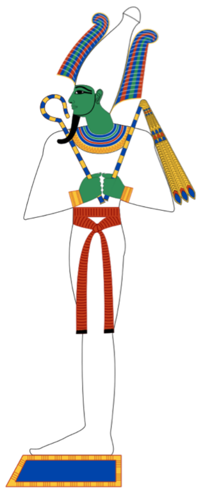
- Launched on Sep. 8, 2016
- Arrival to Bennu: Dec. 2018
- Sample collection: Jul. 2020
- Sample return on Sep. 24, 2023

Cost: ~$1 billion

PI: Dante Lauretta (Univ. of Arizona)

What is Osiris?

God of afterlife, the underworld, and rebirth in Egyptian myth.



What is Hayabusa (隼) 2?

JAXA (Japan Aerospace Exploration Agency) mission to explore a near-Earth object, 162173 Ryugu.

The successor of the Hayabusa spacecraft (2003-2010), another sample-return mission who visited a near-Earth asteroid 25143 Itokawa.

Mission timeline:

- Launched on Dec. 3, 2014
- Arrival to Ryugu: Jun. 27, 2018
- Depart after sample collection: Dec. 2019
- Return to Earth: Dec. 2020

Cost: ~$150 million

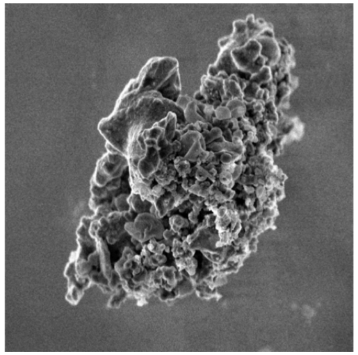
Why sample return mission?

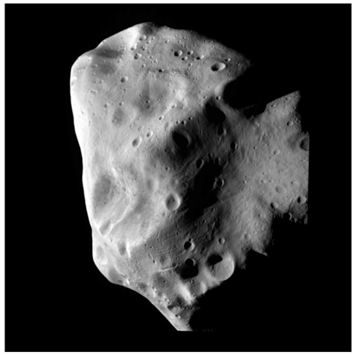
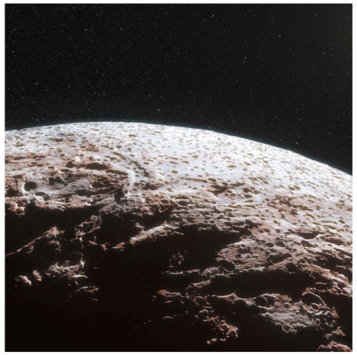
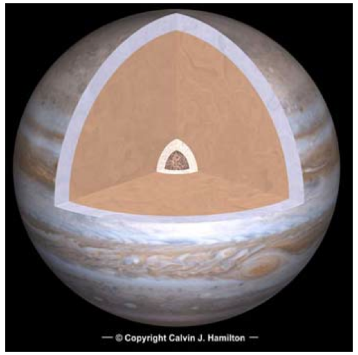
- Scientific tools available on Earth are generally far more advanced and diverse than those that can go on spacecrafts.
- Allows for follow-up studies for any findings with different tools.
- Allows for direct comparison and calibration against findings of remote sensing.
- Direct search for evidence for building blocks of life.

Asteroids: origin

Minor bodies of the solar system, most of which presumably shattered fragments of planetesimals which fail to grow large enough to become planets.

Pathway to planets:



μm | cm | km | 10^3km | 10^5km

Grain growth

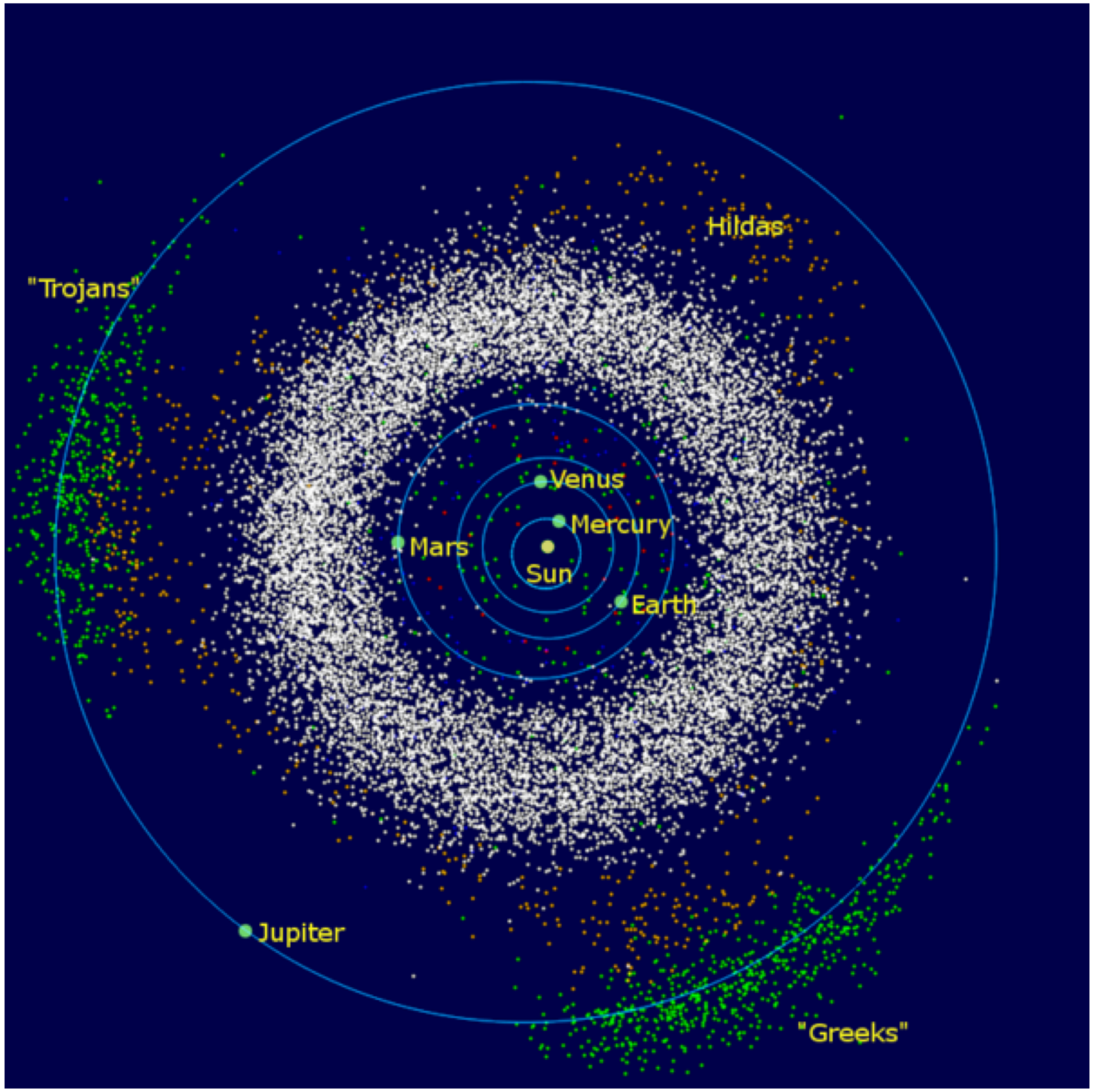
Planetesimal formation

Planetesimal growth to cores

growth/accretion to gas giants

Failed planets or shattered planet(esimal)s

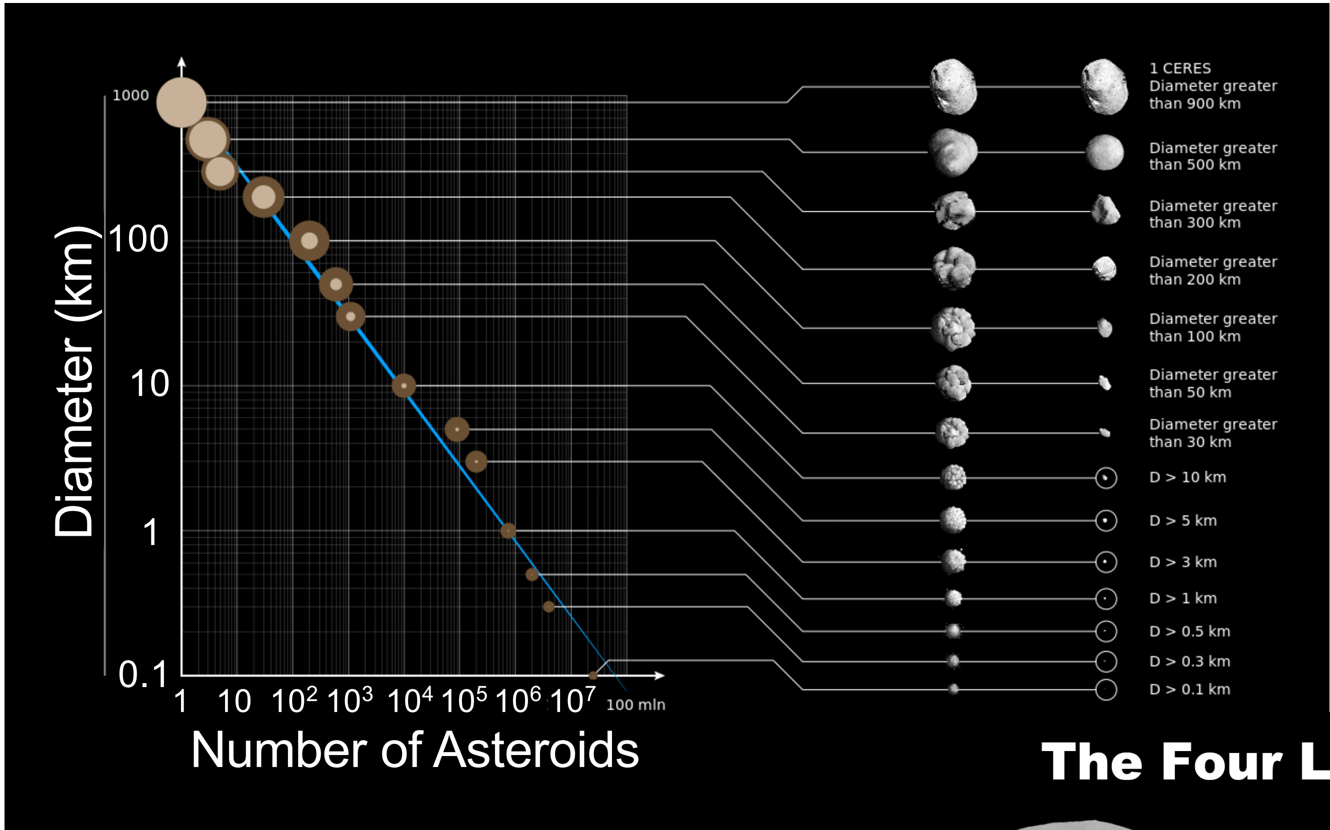
Asteroids: spatial distribution



- Asteroid belt (between Mars and Jupiter, mostly 2.1-3.3 AU)
- Trojans (at L_4/L_5 points w.r.t. a planet, most notably Jupiter)
- Near-Earth objects (some are potentially hazardous)

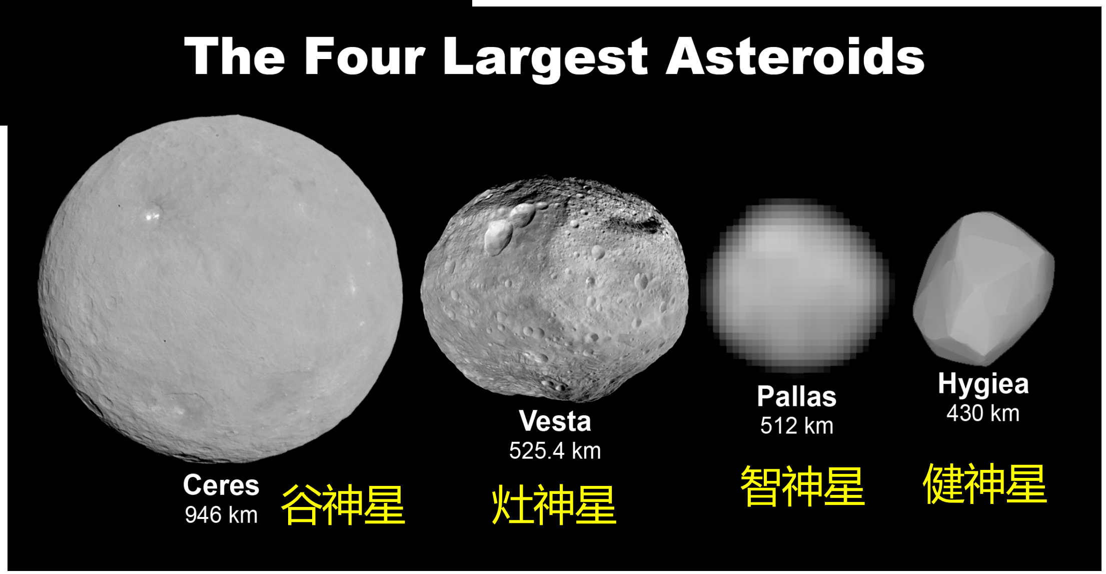
There is also the Kuiper belt, analog of the asteroid belt for the outer solar system.

Asteroids: size distribution



Power-law with additional features at ~5, 100 km

Vast majority are small ones.

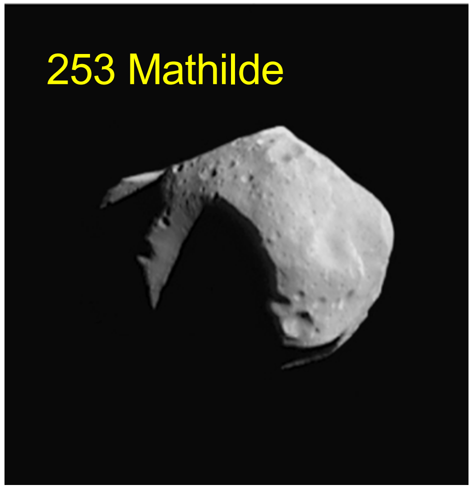


Asteroids: composition and classification

Asteroids are classified according to their emission spectrum, color and albedo.

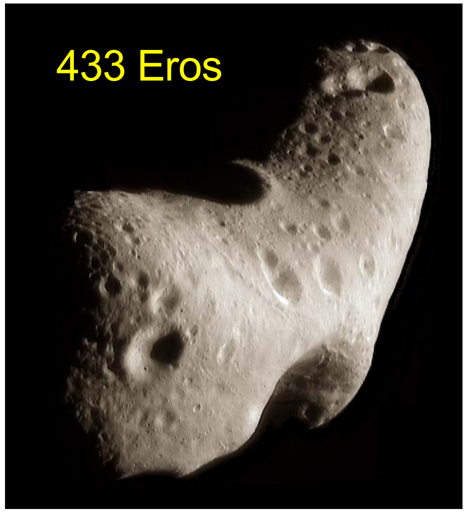
These reflect their composition, which is known to vary greatly, but they are not necessarily accurate indicators of composition (due to e.g. space weathering).

The most common spectral types are:



C-type (carbonaceous; ~75%)

More in the outer belt > 3 AU

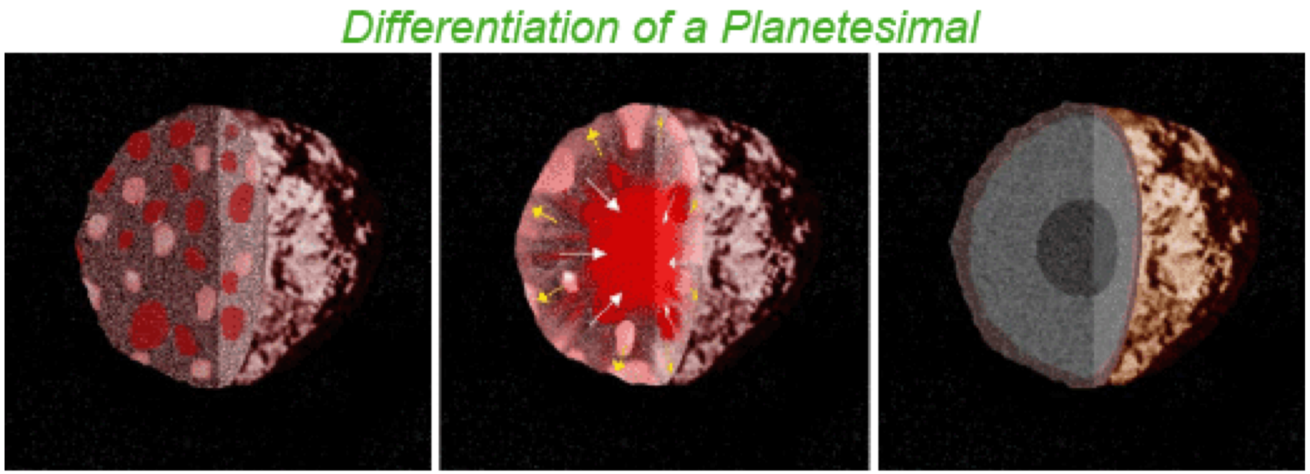


S-type (silicate/stony; ~17%)

More in the inner belt < 3 AU

Asteroids: internal evolution

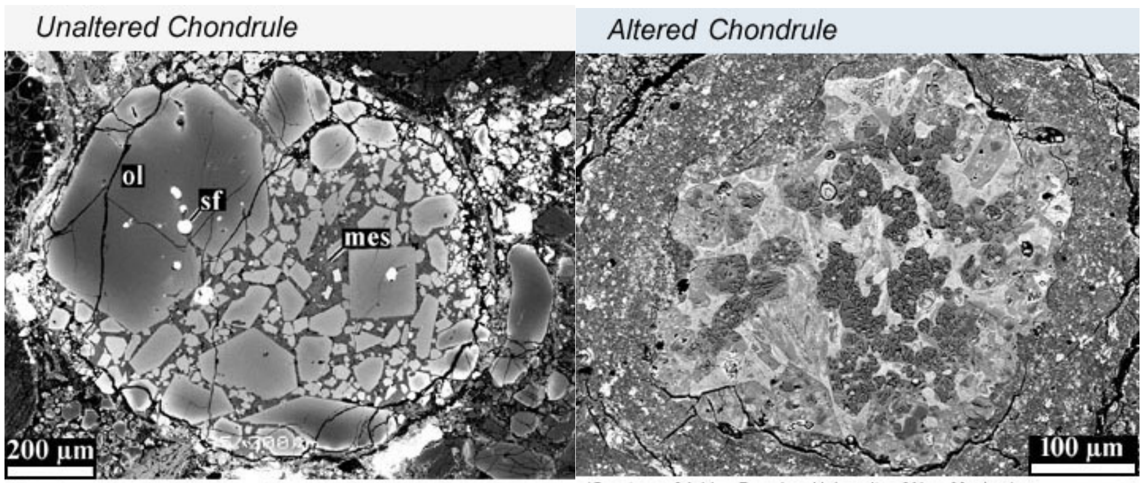
Differentiation
(massive objects + radioactive heating):



(Frank Granshaw, Artemis Software)

Metamorphism: the change of minerals or geologic texture in rocks due to heating / pressure / chemically active fluids while remain solid.

Aqueous alteration: change in chemical/mineralogical composition of a rock due to interactions with H_2O-bearing ices/liqueds or vapors.

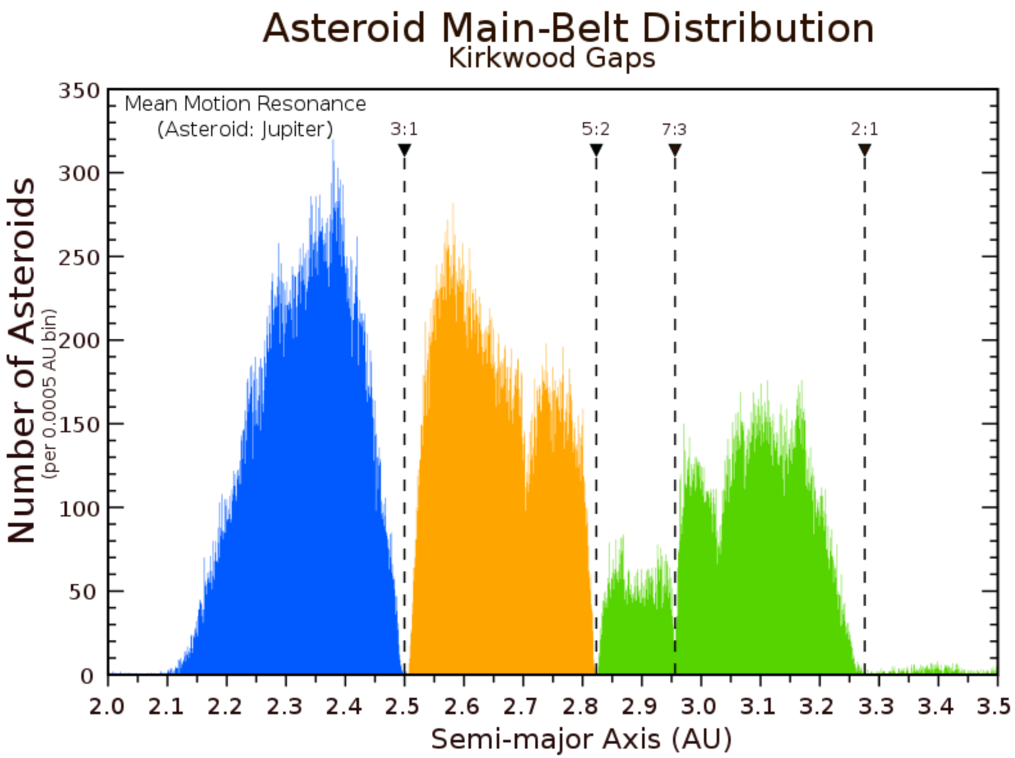


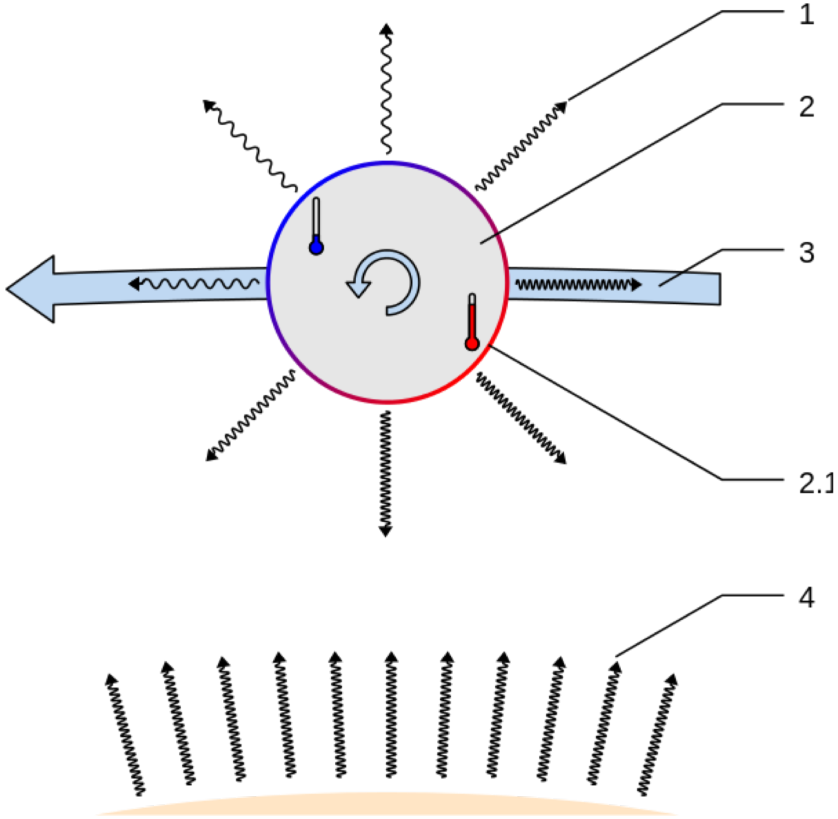
(Courtesy of Sasha Krot, University of Hawaii.) (Courtesy of Adrian Brearley, University of New Mexico.)

Asteroids: dynamical evolution

Dynamical interaction with major bodies (e.g., Jupiter);

Collisions and fragmentation, etc.



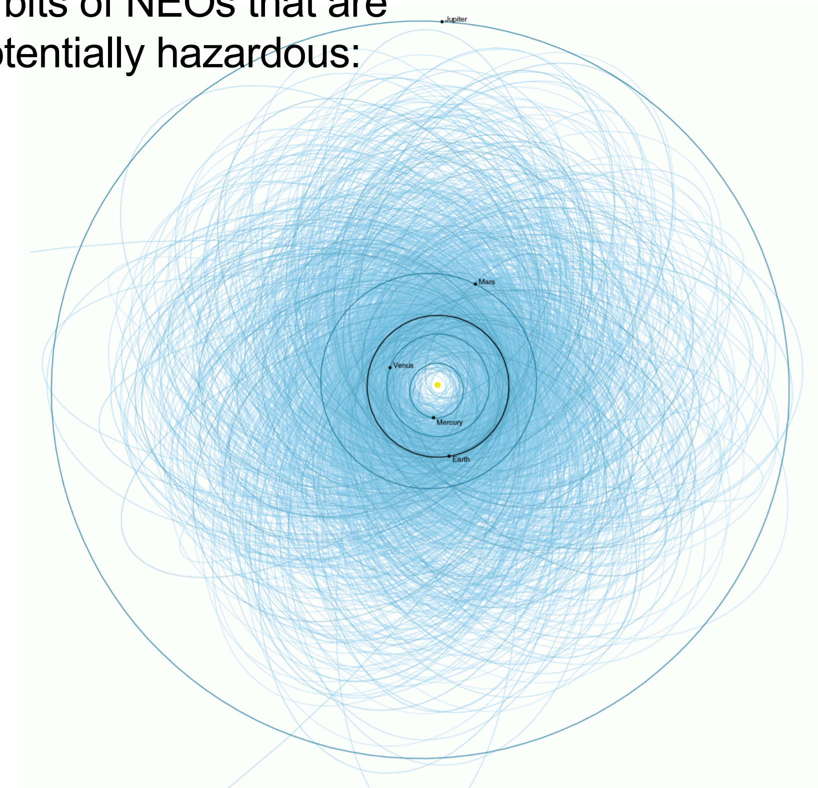


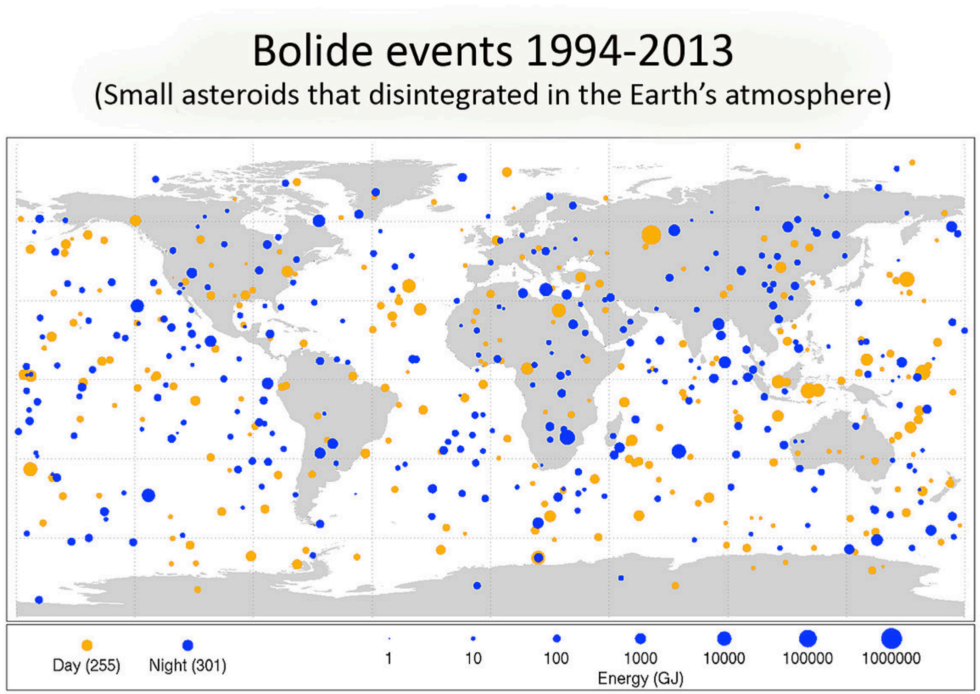
Yarkovsky effect

=> Orbital drift (at uncertain rates depending on shape/rotation)

Near earth objects and meteorites: origin

Orbits of NEOs that are potentially hazardous:





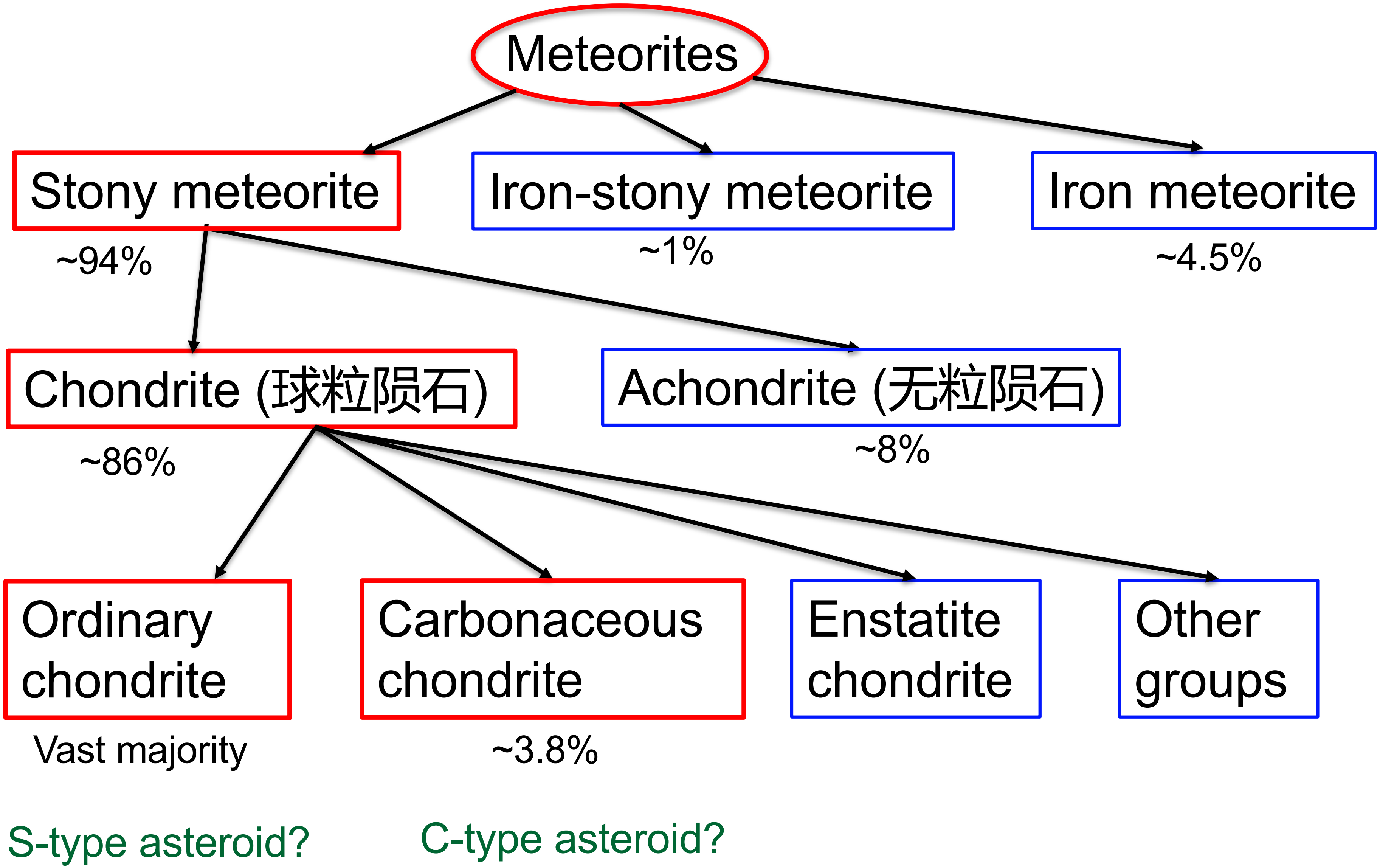
Many of these objects end up as NEOs / meteoroids by:

Asteroid collisions in the main belt produce fragments

Some fragments, after some evolution, enters orbital resonance with Jupiter.

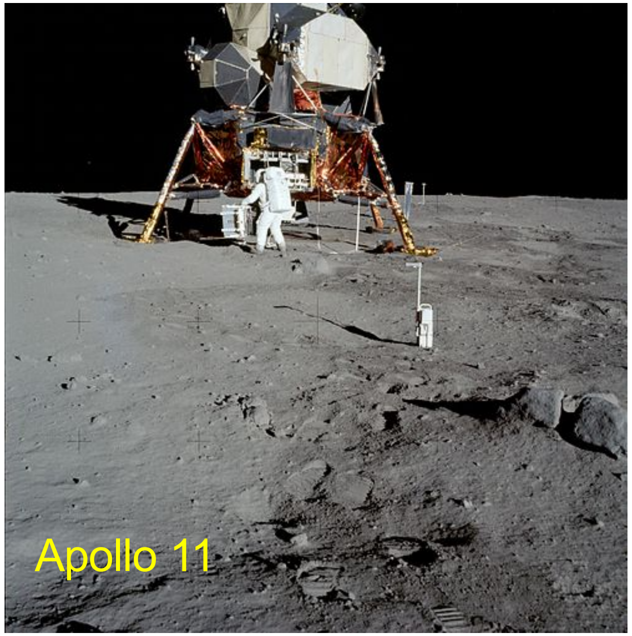
This increases their orbital eccentricity, eventually crossing the Earth's orbit.

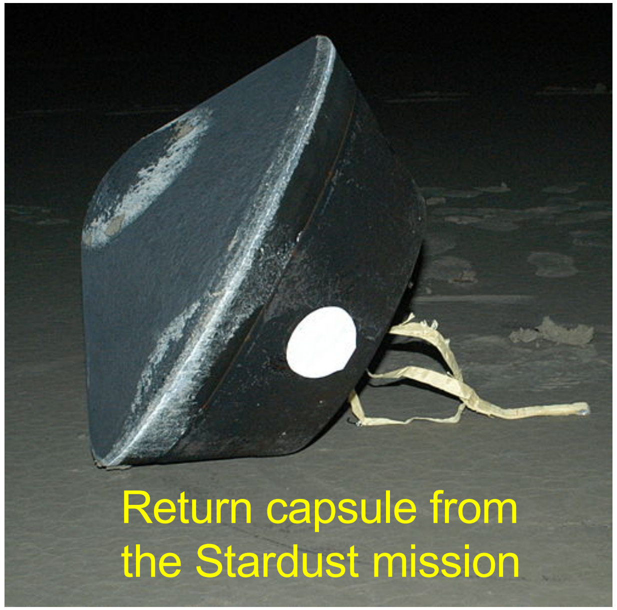
Meteoritics: classification



Solar system samples collected to date

- Apollo and Luna samples from the moon (1970s)
- Solar wind samples by the Genesis mission (2000s)
- Asteroid samples from the Hayabusa mission (2000s)
- Comet samples from the Stardust mission (2000s)
- Meteorites (some have identified parent bodies including Mars, Vesta).



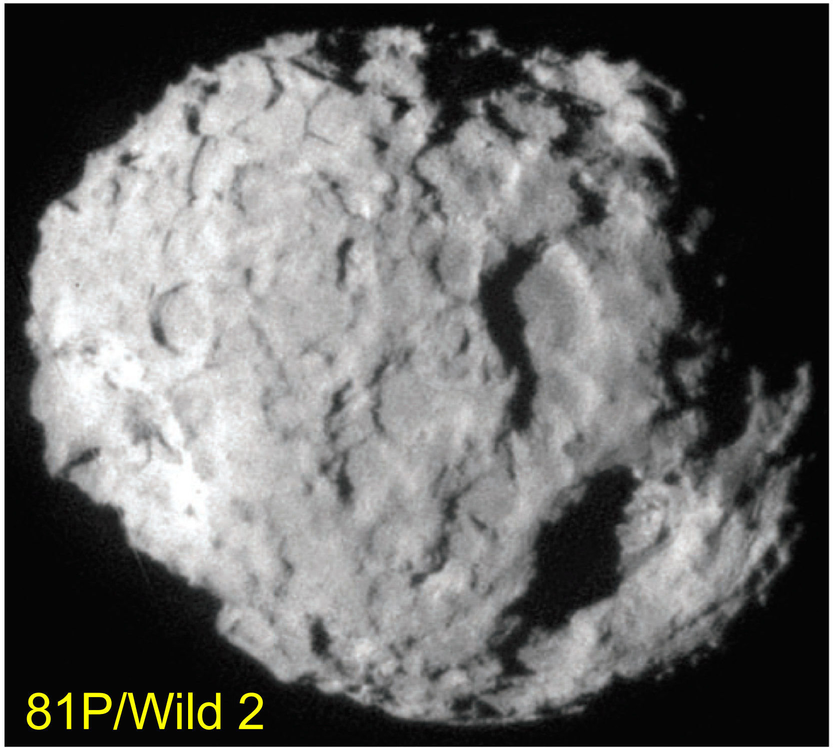


Stardust mission (NASA)

Main target: comet 81P/Wild 2
(extended mission visited Temple 1)

Orbital period changed from 43 years to 6 years after encounter with Jupiter in 1974.

Launched in 1999, flew by on Jan. 2004, collecting particles from the coma (using aerogels), returning to Earth on Jan. 2006.



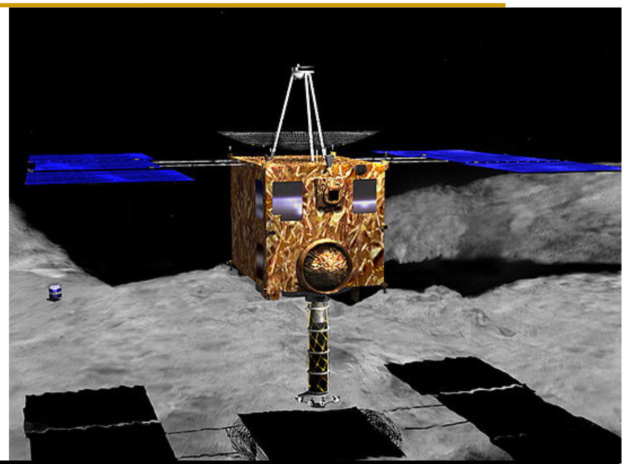
Major (surprising) findings:

Almost all micron+ sized grains are formed in the solar system (not inherited).

Presence of crystalline silicates (particularly olivine and pyroxene) that must be made under very high temperatures => large-scale mixing from inner solar system

A wide range of organic compounds, particularly glycine (甘氨酸).

Hayabusa mission (JAXA)



Main target: asteroid 25143 Itokawa

S-type (S: silicate/stony) asteroid in the inner asteroid belt.

Launched in 2003, arrived, landed and collected samples in 2005, returning to Earth on 2010.

Major findings:

The mineralogy and mineral chemistry of Itokawa dust particles are identical to those of thermally metamorphosed LL chondrites (a type of ordinary chondrites).

=> Confirmation of the link between ordinary chondrites and S-type asteroids.

=> This asteroid used to be in the interior of a much bigger asteroid.

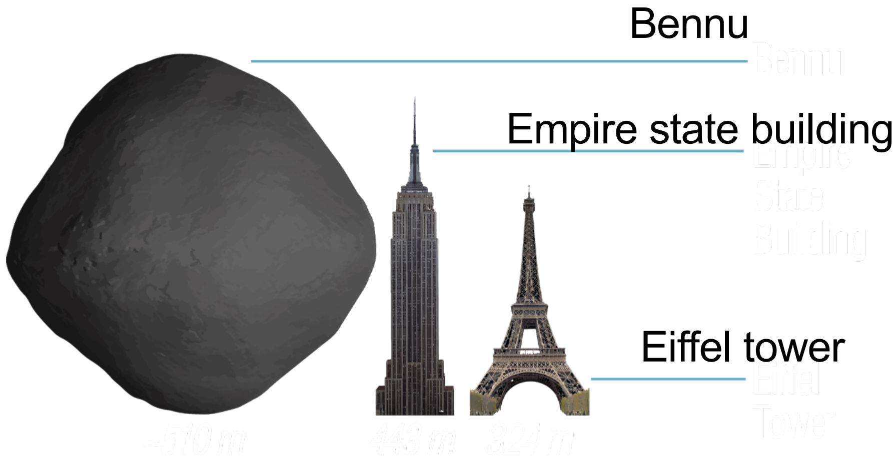
Target of OSIRIS-Rex: Bennu

Diameter: ~500m

Orbital period: ~1.2 years

Orbital distance: 0.90-1.36 AU

Rotation period: ~4.3 hours



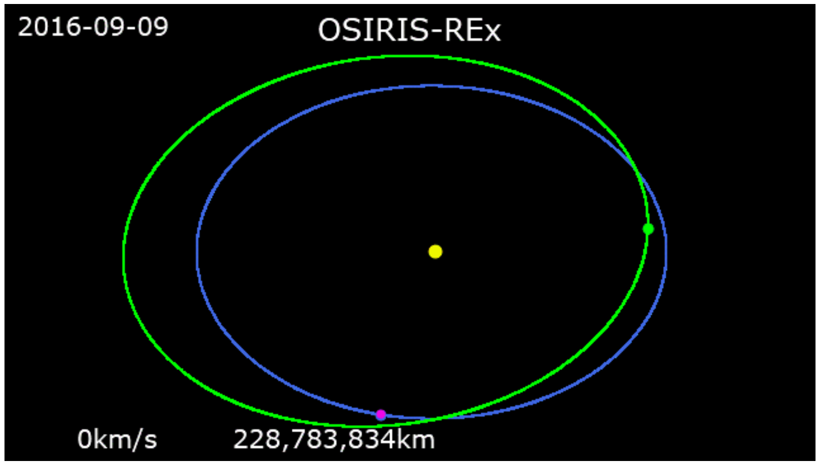
Classification: B-type asteroid (similar to C-type but more primitive)

Carbonaceous, pristine, likely contain rich organic materials

One of the most potentially hazardous object.

Encounter with the Earth every 6 years.

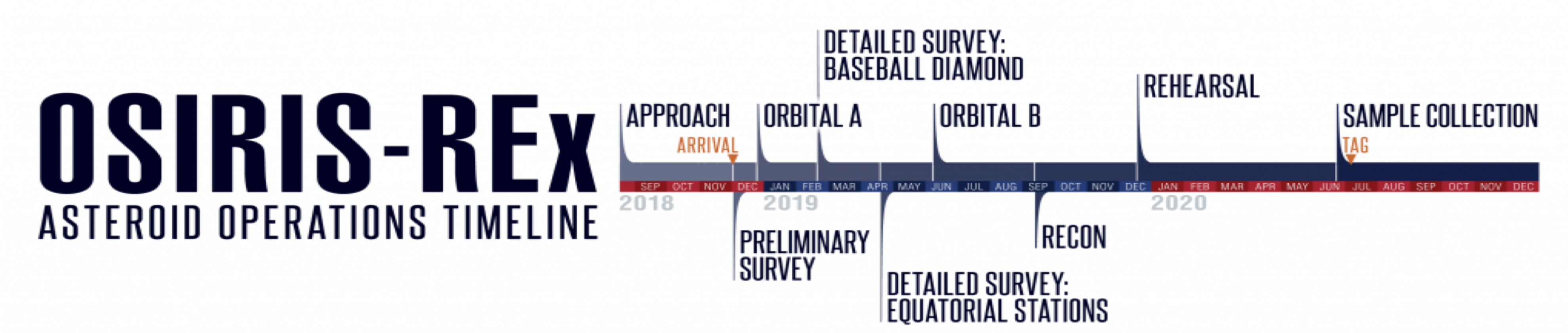
Chance of impact ~1/2700 in 2175-2199



OSIRIS-REx : scientific objectives

Origins, **S**pectral **I**nterpretation, **R**esource **I**dentification, **S**ecurity, **R**egolith **Ex**plorer

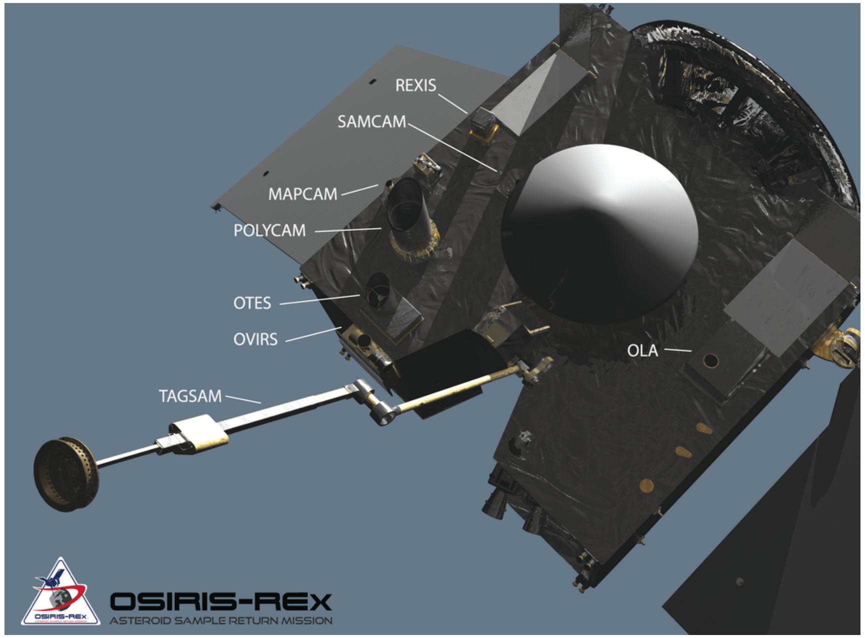
- **Origins:** Sample return to study its minerals /organic materials (origins of life / solar system)
- **Spectral Interpretation:** Define global properties to calibrate ground-based observations
- **Resource Identification:** Map its chemistry /mineralogy to define its geologic and dynamic history
- **Security:** Measure the Yakovsky effect
- **Regolith Explorer:** Document the texture, morphology, geochemistry and spectral properties of the regolith at sample site



OSIRIS-REx: science payloads

OCAMS (CAMera Suite):

Three instruments for: global mapping, surveying sample sites, high-res imaging, recording sample acquisition.



OLA (Laser Altimeter):

High-res tomographic information.

OVIRS (Visible and InfraRed Spectrometer):

Provide mineral and organic spectral data at 0.4-4.3 μm with 7.5-22 nm spectral res.

OTES (Thermal Emission Spectrometer):

Similar to OVIRS, but work at 5.7-100 μm to characterize emission properties.

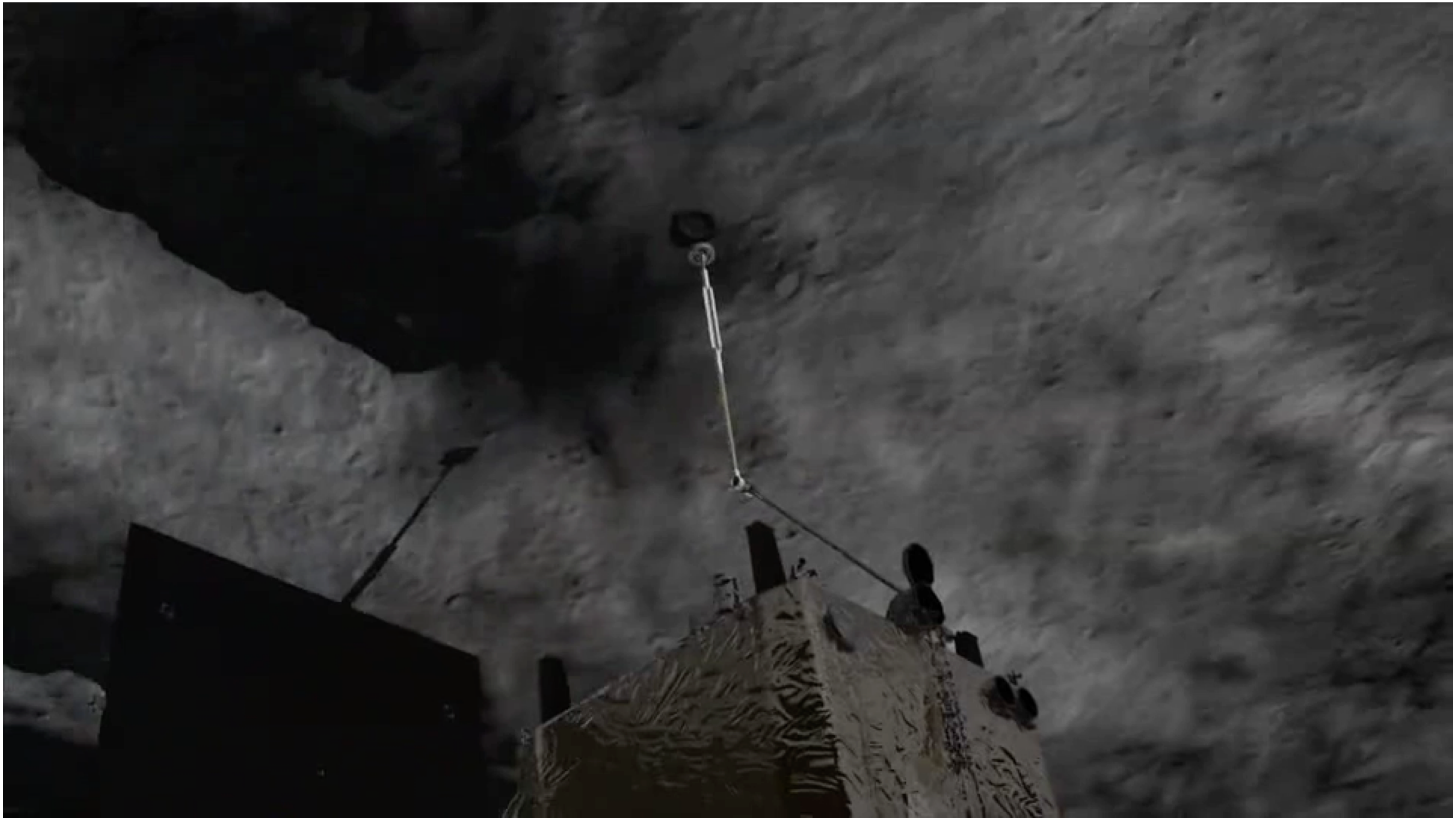
REXIS (Regolith X-ray Imaging Spectrometer):

Soft X-ray telescope that images X-ray fluorescence line emission to constrain elemental abundances.

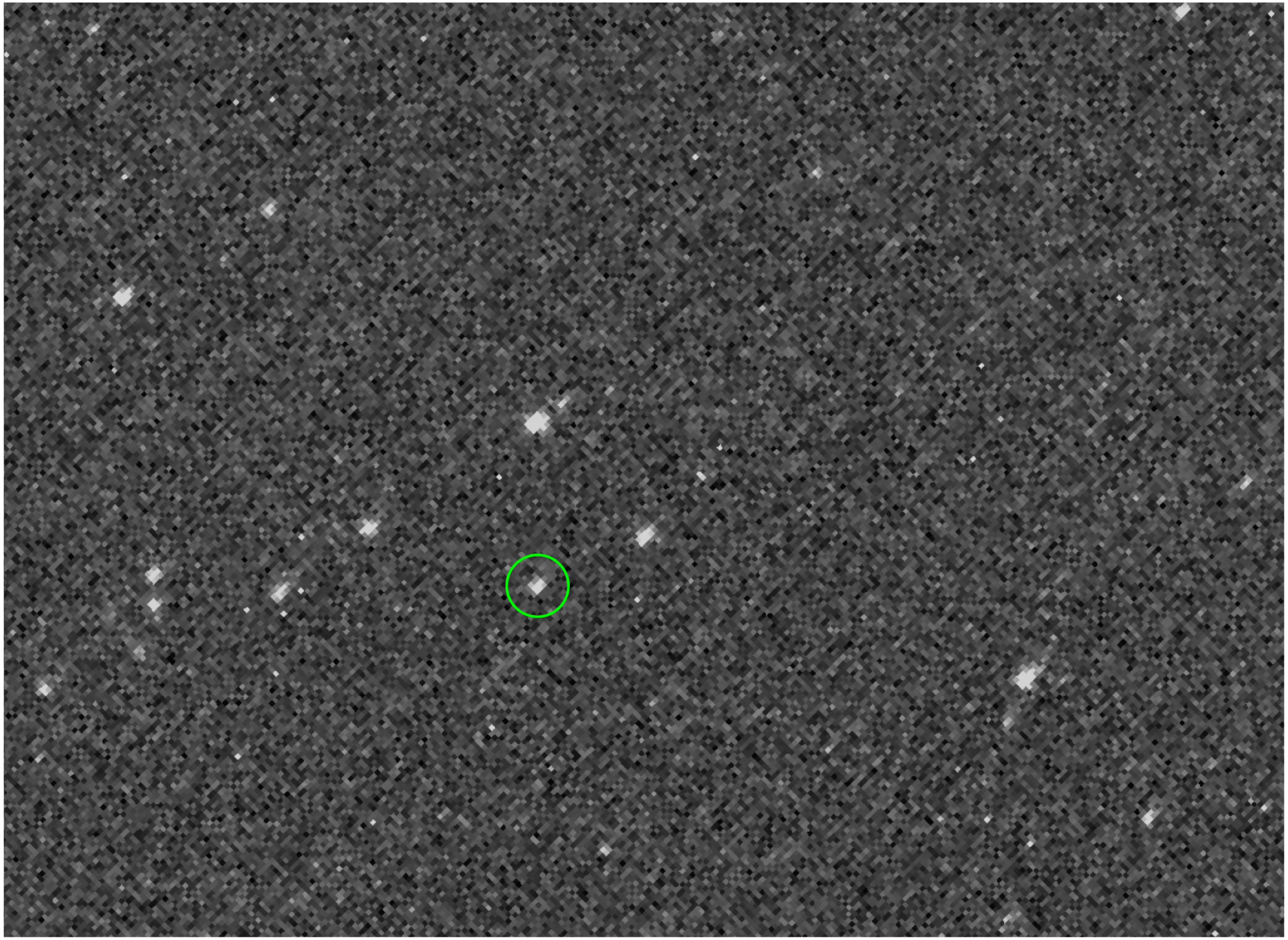
Run by MIT and Harvard students!

OSIRIS-REx: sample return operations

TAGSAM: Touch-And-Go Sample Acquisition Mechanism



OSIRIS-REx: current status



Final approach towards Bennu (Aug. 24, 2018), to arrive on Dec. 3, 2018

Hayabusa 2: target and mission objectives

Classification: Cg-type asteroid (a sub-type of C-group)

Diameter: ~900m

Orbital period: ~1.3 years

Orbital distance: 0.96-1.41 AU

Rotation period: ~7.6 hours

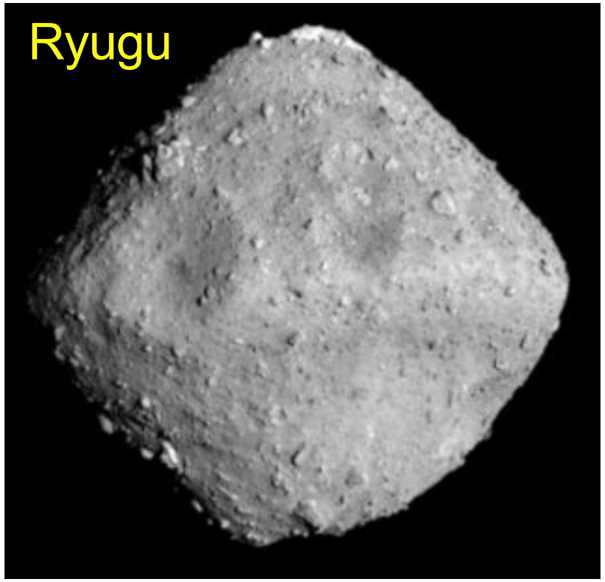


Image taken by Hayabusa 2

Scientific significance:

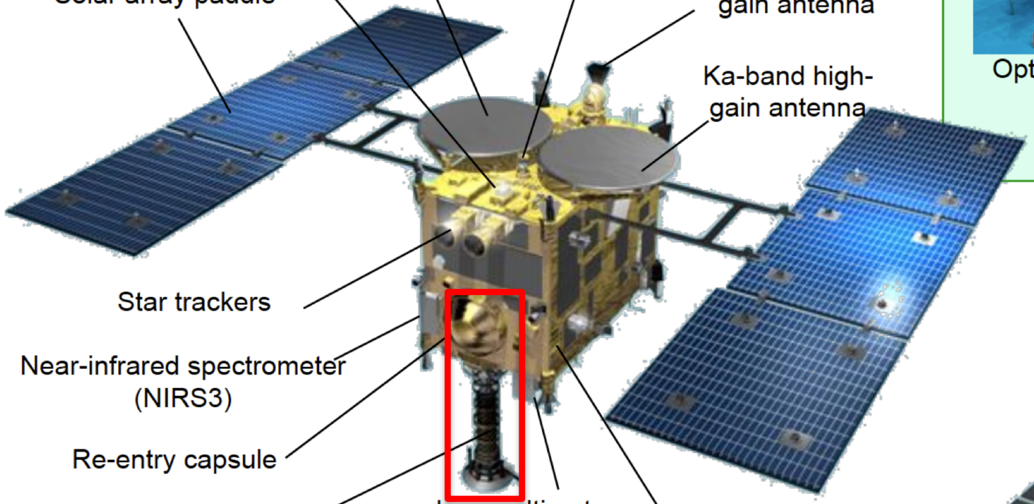
Elucidate the origin and evolution of the solar system and building blocks of life.

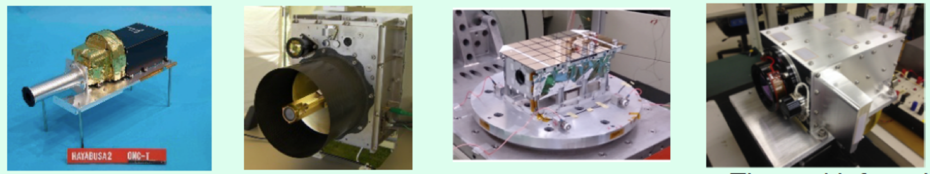
Technological significance:

Built upon Hayabusa, bring the ion engine technology towards maturity.

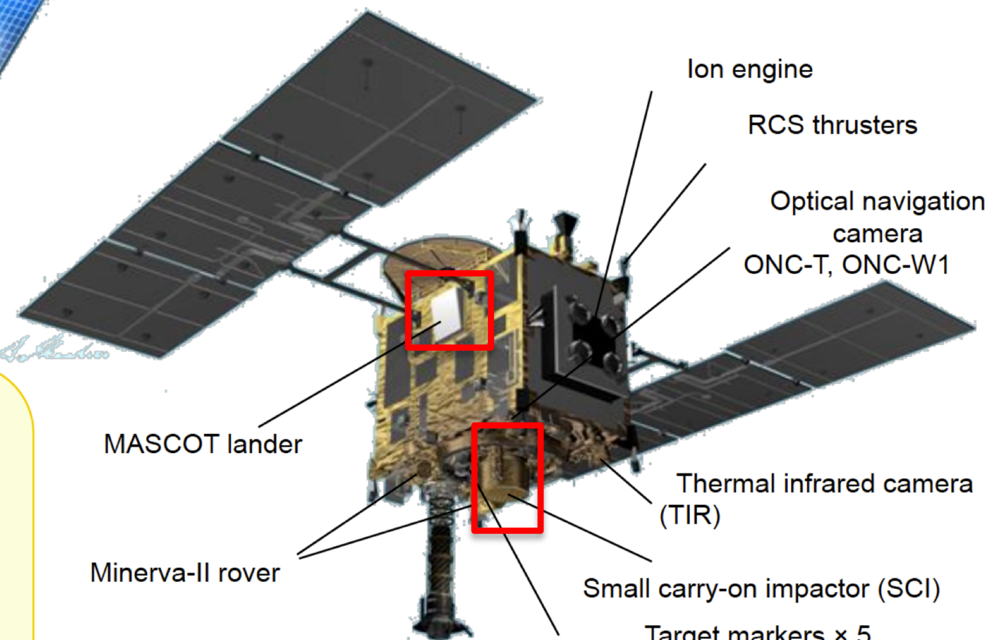
Demonstration of the space impactor technology.

Hayabusa 2: science payloads



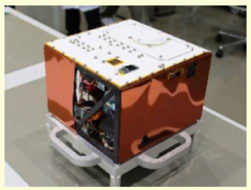


Scientific observation equipment



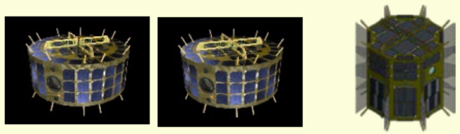
Small lander & rover

MASCOT



Created by DLR and CNES

Minerva 2



II-1A II-1B II-2

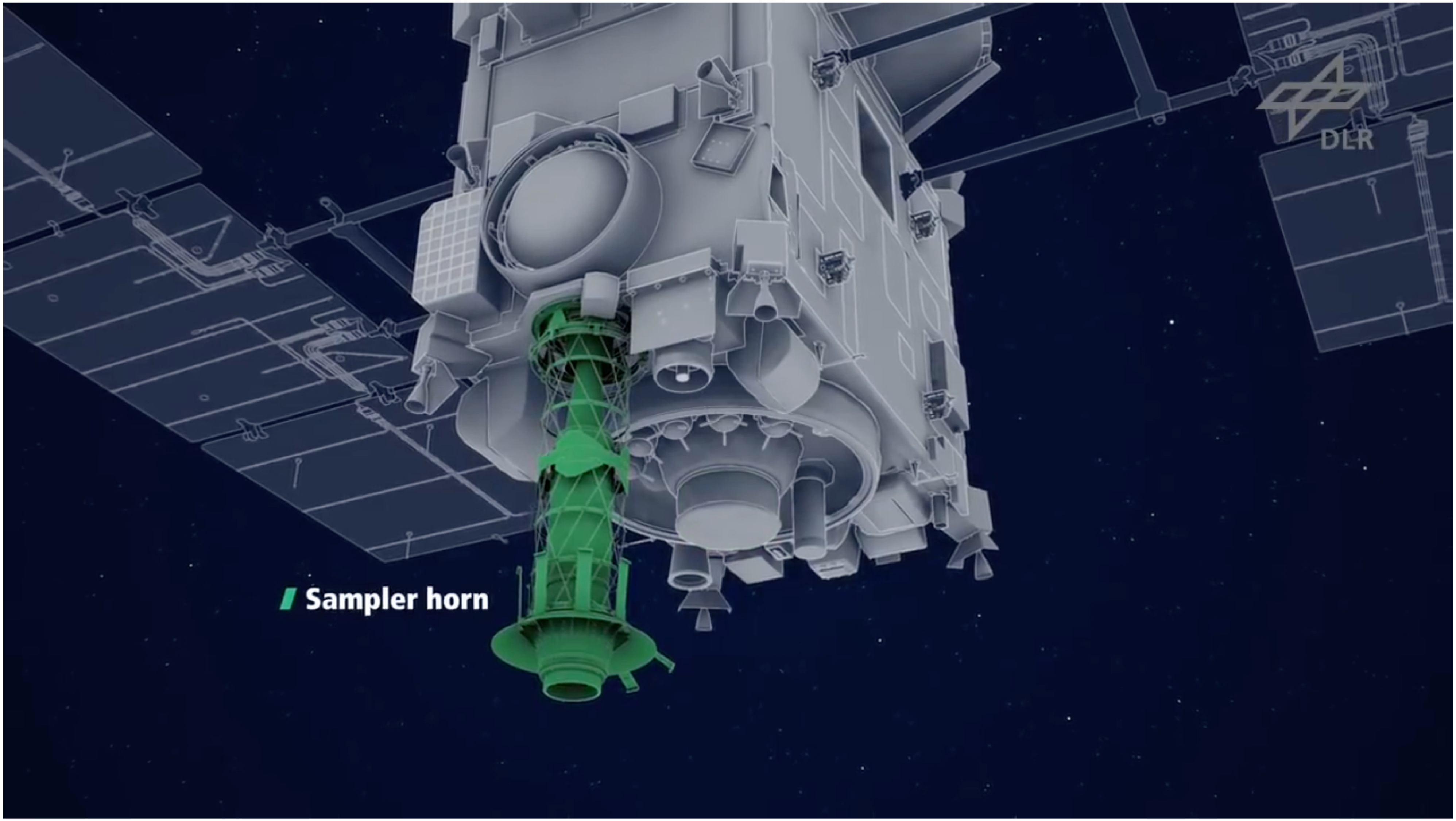
II-1: By the JAXA Minerva-II team

II-2: By Tohoku Univ. & the Minerva-II Consortium

Size: 1 ×1. 6×1. 25 m (main body)
Solar paddle deployed width 6 m
Mass : 609 kg (incl. fuel)

(from JAXA website)

Hayabusa 2: sample return operations



https://www.youtube.com/watch?v=b9fITBmQt1Y

Hayabusa 2: current status

Arrived on Jun 27, 2018
(at altitude of 20 km)!

Now in the process of remote sensing the asteroid at a distance of 1-5 km, followed by a decision of landing site.

http://www.hayabusa2.jaxa.jp/topics/20180629je/index_e.html

Summary

- Sample return missions from asteroids are a unique way to learn about solar system origins, and origins of life.
- Asteroids show diverse properties owing to complex formation scenarios, as well as internal and dynamical evolution.
- OSIRIS-REx: NASA mission to explore Bennu, a primitive asteroid and bring its surface particles back to the Earth in 2023.
- Hayabysa 2: JAXA mission to explore Ryugu, another primitive asteroid with sample return to the Earth in 2020.
- China is also picking up the speed, aiming to explore a near Earth objects in the near future.

References

OSIRIS-REx:

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https://en.wikipedia.org/wiki/OSIRIS-REx

Hayabusa 2:

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http://global.jaxa.jp/projects/sat/hayabusa2/

https://en.wikipedia.org/wiki/Hayabusa2

Others:

Nakamura et al. 2011, Science, 333, 1113

Brownlee, 2014, AREPS, 42, 179

With most figures taken from wikipedia.