# The asteroid sample return mission “Hayabusa2” and its activity of SMA

Satoru NAKAZAWA (JAXA)
and Haybusa2 project team

# Satoru Nakazawa

- Career
  - Engineering: System engineer (mission instruments, TCS, EMC, etc.)
  - Management: Deputy Manager of Hayabusa2 project team

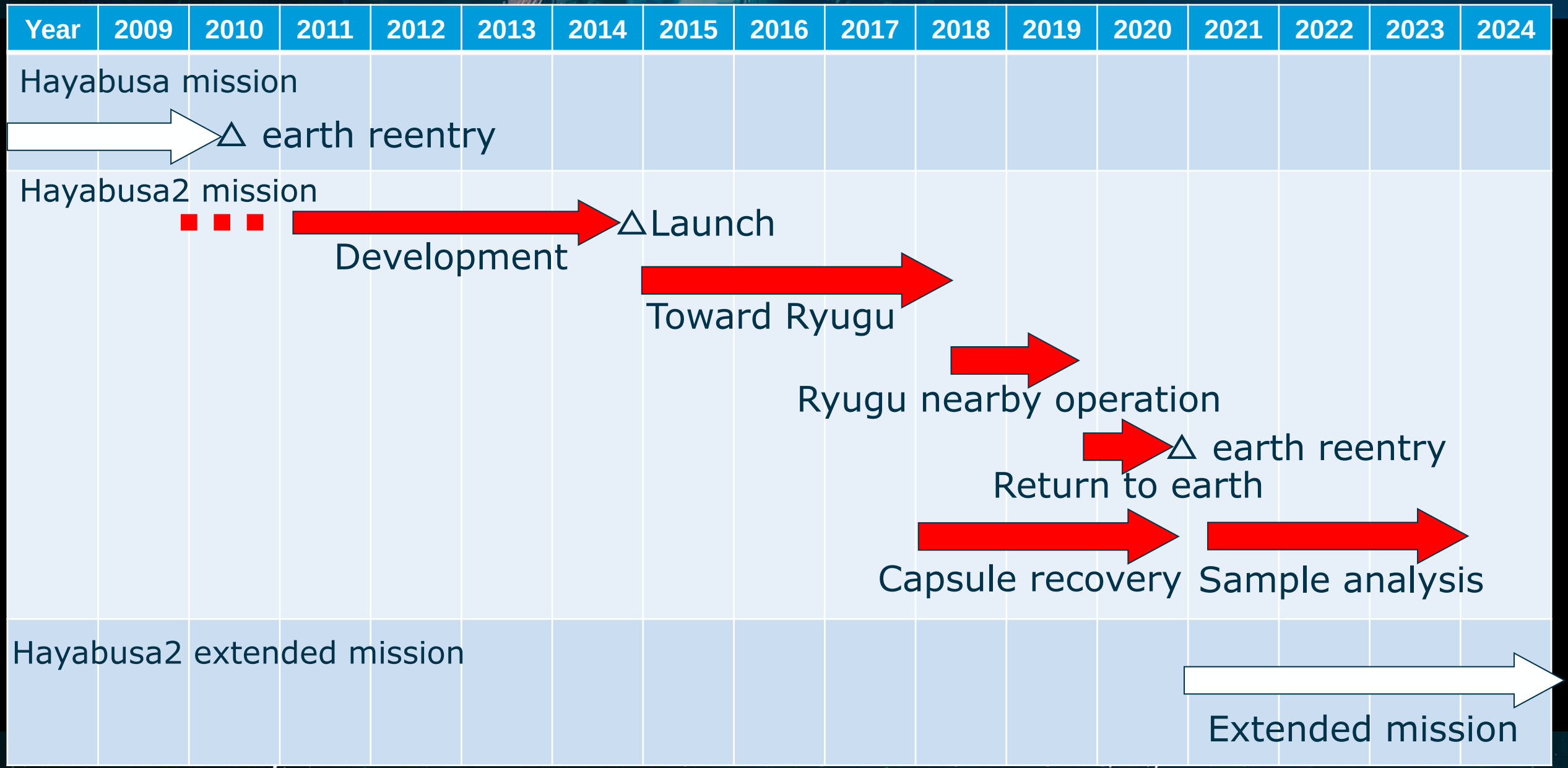
- Experienced Mission
  - Lunar Explorer “KAGUYA (SELENE)”, 2007-2009.
  - Mercury mission BepiColombo “Mio (Mercury Magnetospheric Orbiter)”, 2018-.
  - Asteroid sample return mission “Hayabusa2”, 2014-

# Agenda

1. Hayabusa2 mission
2. The S&MA activity of Hayabusa2
3. Hayabusa2 Extended mission

# 1. Hayabusa2 mission

# 1. Hayabusa2 mission: Chronology



# 1. Hayabusa2 mission: Development

- Asteroid sample return mission “Hayabusa”: Launched in 2003, Return to earth in 2010
- Target asteroid: Itokawa (S-type)
- The first mission in the world to successfully return asteroid sample.
- But, many troubles;
  - failed in release of rover “MINERVA”,
  - 2 of 3 RWs failed,
  - unplanned landing on the asteroid,
  - sampling projectile was not fired,
  - the fuel leaked,
  - all four ion engines failed.

- Overcoming these troubles, ”Hayabusa” was finally succeeded in return to earth and brought the asteroid sample.
- The recovery skill was so creative, but the technology and the operation was not perfect.

# 1. Hayabusa2 mission: Development

- Immediately after returning, the following mission “Hayabusa2” was begun.
- Target asteroid: Ryugu (C-type)
- Design policy of Hayabusa2
  - To follow the basic design and the operation of Hayabusa.
  - To investigate the cause of the problem and to take measures
  - To challenge additional new technology

Hayabusa

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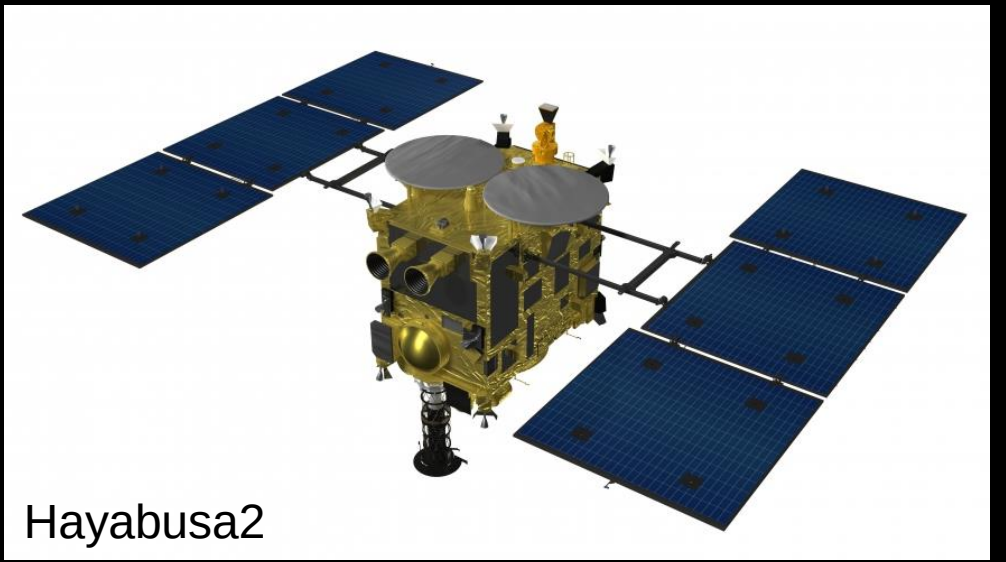

Hayabusa2

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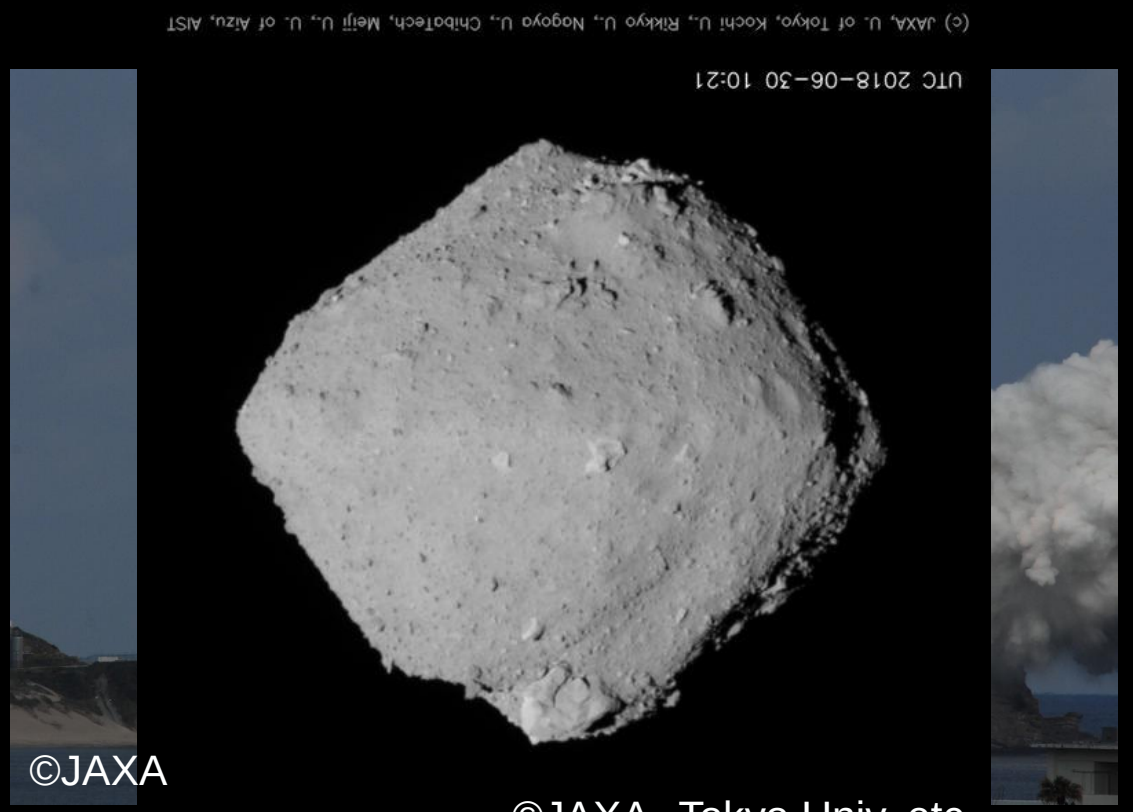
# 1. Hayabusa2 mission: Arrival

- Launch window for Ryugu was very limited. We rushed to complete the manufacturing in three years.
- Dec. 2014: Launched by H-IIA rocket from Tanegashima space center.
- June 2018: Arrived at Ryugu with using ion engine and earth swing-by.

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23 June 2018 ©JAXA、Tokyo Univ. etc.

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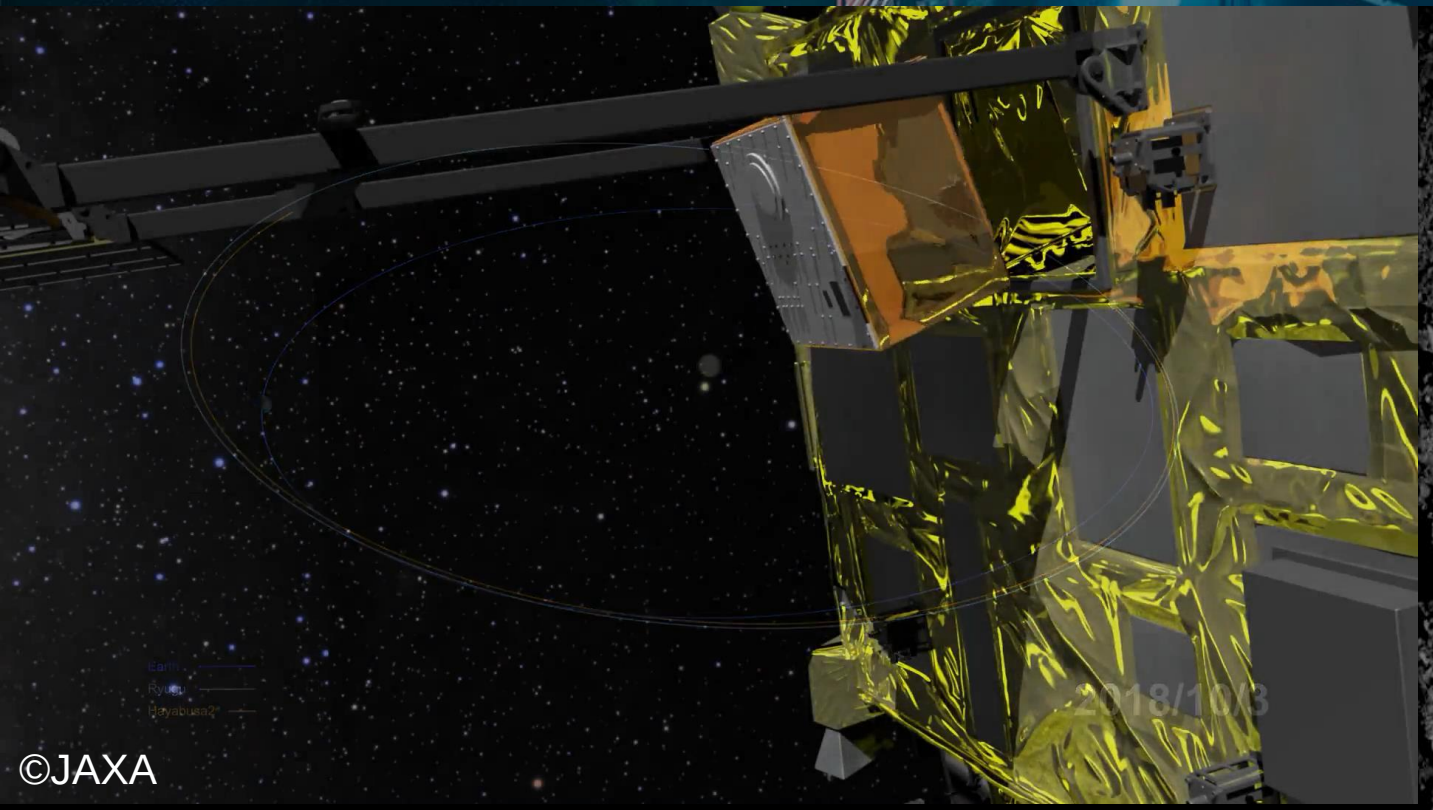
# 1. Hayabusa2 mission: MASCOT



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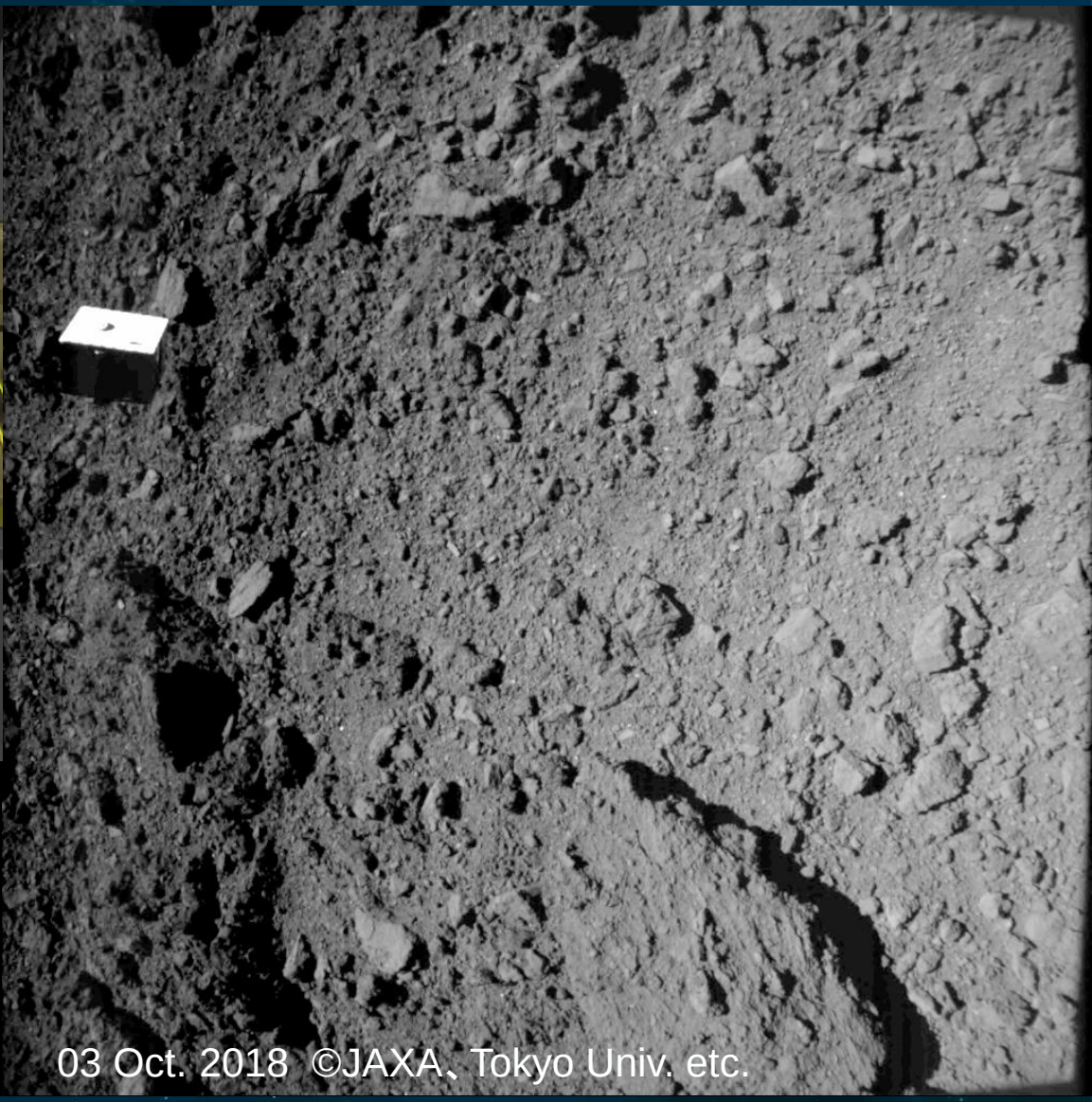
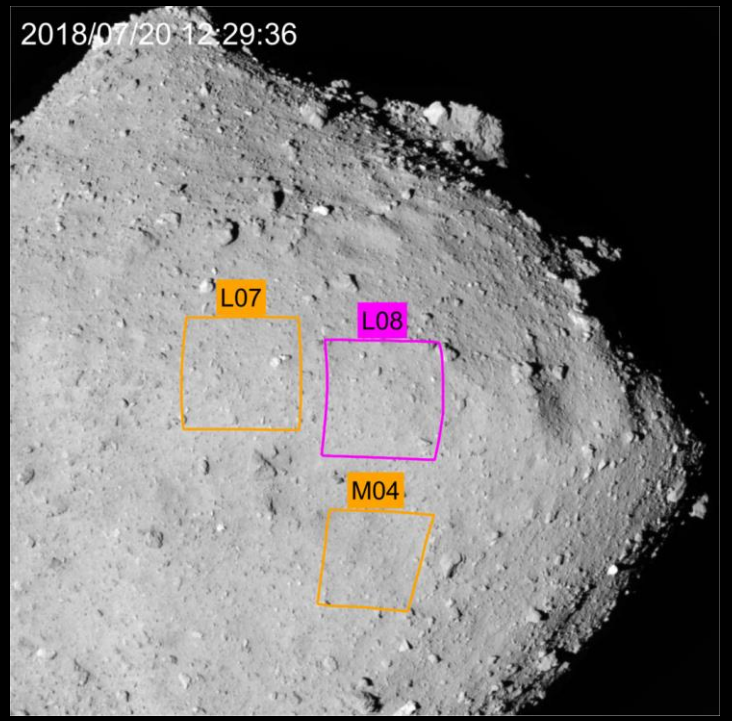
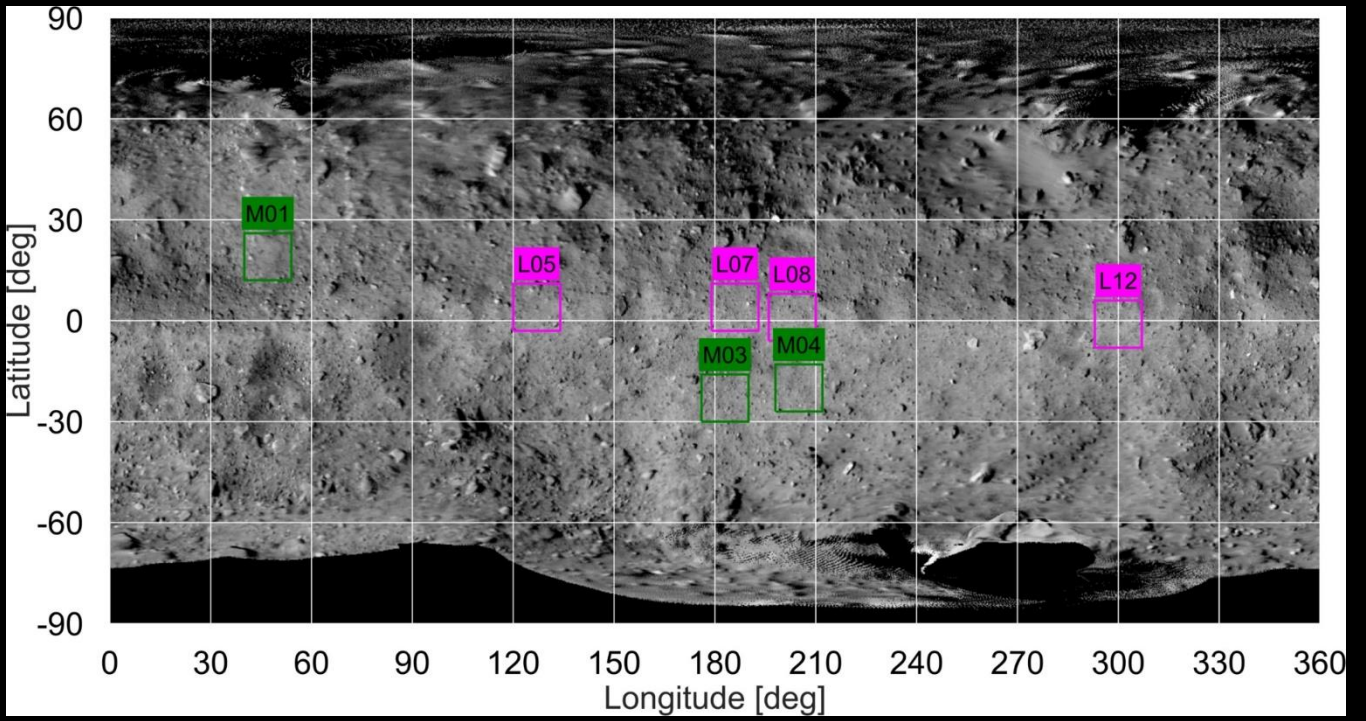

03 Oct. 2018 ©JAXA、Tokyo Univ. etc.

- Before touchdown operation, we released lander MASCOT which was developed by DLR and CNES.
- It was equipped with impressive analytical instrument and got excellent scientific results.

# 1. Hayabusa2 mission: Touch down

- Surprised that Ryugu was very rough.
- A rock of several meter high can crash the spacecraft at the touchdown.
- While the original landing accuracy: 100m × 100m, there was no such wide flat area.
- Postponed the touchdown schedule, and improved the accuracy, searched small but flat area.




Landing accuracy (100mx 100m) ©JAXA, Tokyo Univ. etc.

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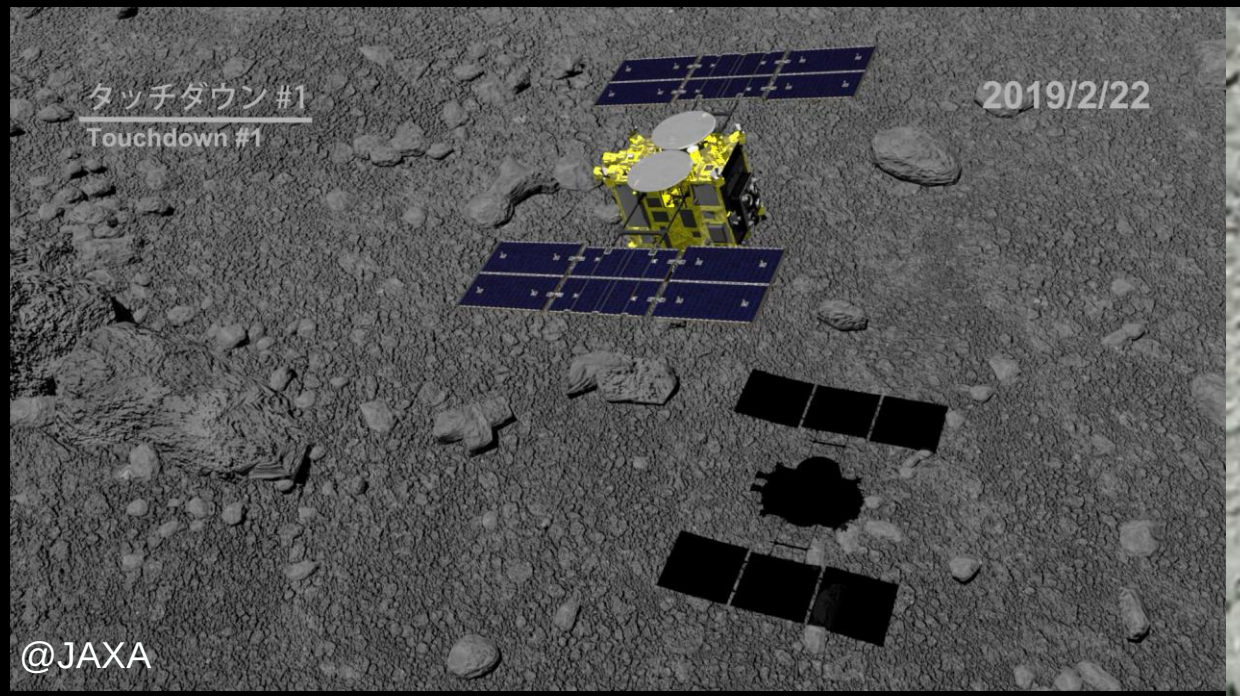
# 1. Hayabusa2 mission: Touch down

- After significantly improving the touchdown strategy, we finally achieved the landing accuracy of 1m.
- Feb. 2019: Touchdown operation.




↑ Virtual image for the touchdown operation.

Real image taken by the onboard monitor camera. →

# 1. Hayabusa2 mission: Touch down

- All member joined the touchdown operation celebrated the success.
- Not only JAXA, but also manufacturing company and university became ”one team”.
- Some were member of Hayabusa. It was a ten-year journey for them to achieve this success.


@JAXA (22 Feb 2019 in the operation room)

# 1. Hayabusa2 mission: Operation

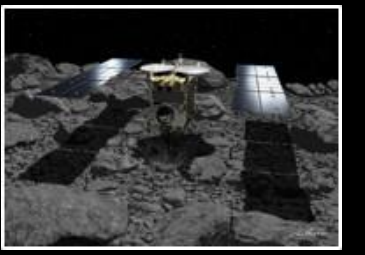
Launch
Dec.3, 2014

Earth Gravity Assist
Dec.3, 2015

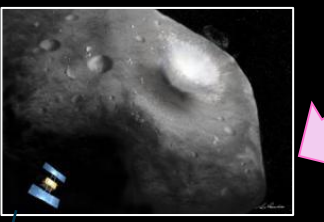
Ryugu Arrival
Jun.27, 2018

MINERVA-II-1
Deployment
Sep.21, 2018

MASCOT
Deployment
Oct.3, 2018



First
Touchdown
Feb.22, 2019



Kinetic Impact
Apr.5, 2019

Second
Touchdown
Jul,11, 2019

Target Markers
Orbiting

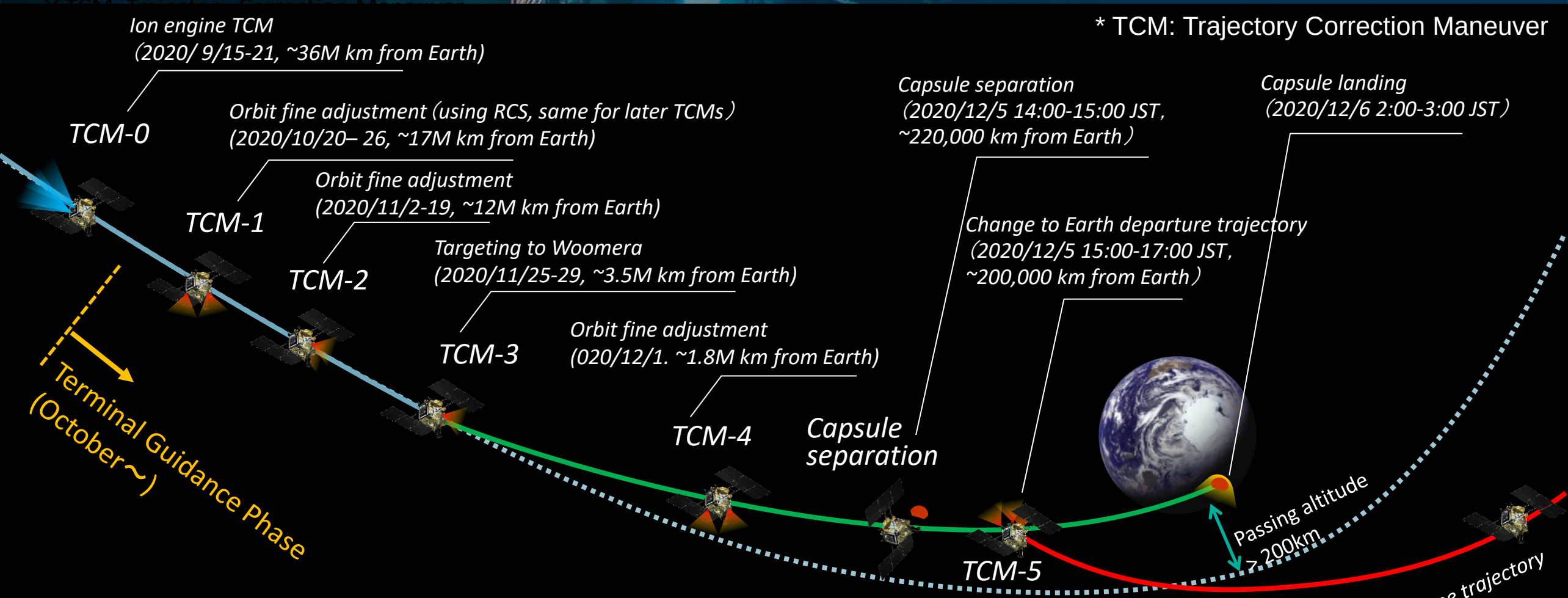
Sep.16, 2019

MINERVA-II-2
Orbiting
Oct.2, 2019

Ryugu Departure
Nov.13.2019

Earth Return
Dec.6, 2020

# 1. Hayabusa2 mission: Reentry sequence

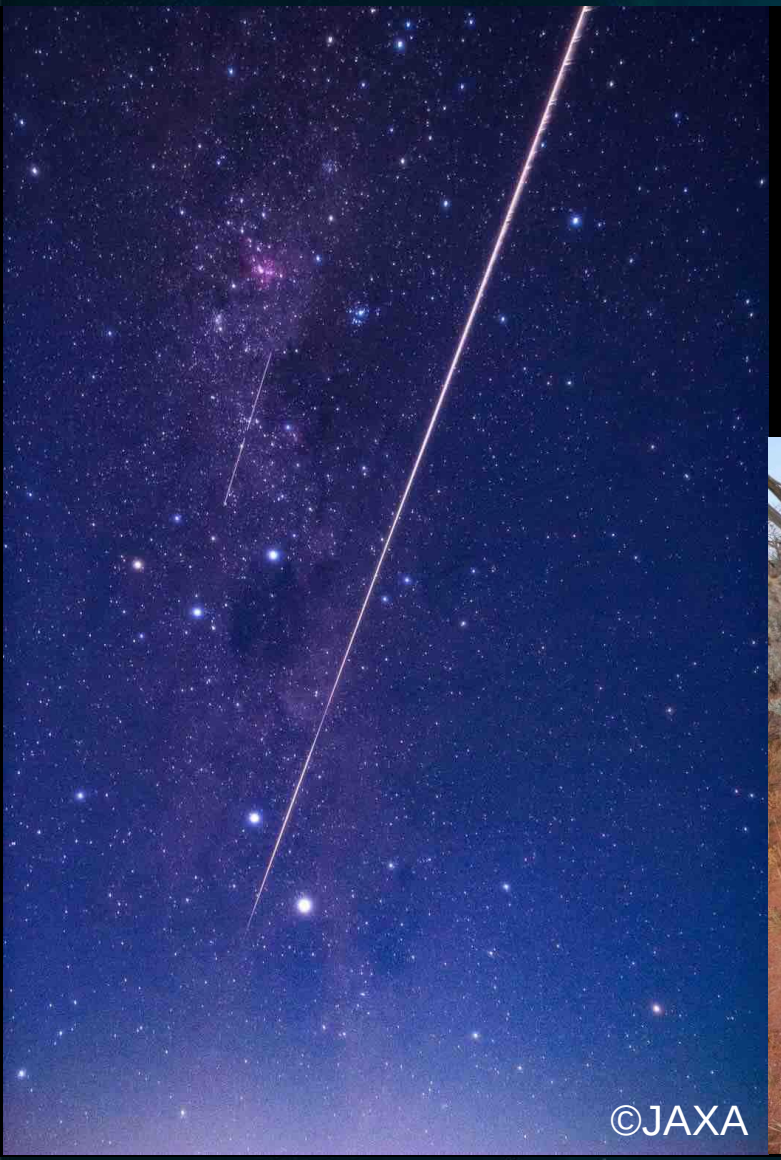



Beginning: the spacecraft was put into an orbit that passed just about 200 km away from the Earth.

TCM-3: the orbit was changed toward earth, Australia. The reentry capsule was separated 12 hours before reentry.

After the capsule separation: the spacecraft diverted from the reentry trajectory, only the capsule re-entered.

# 1. Hayabusa2 mission: Capsule recovery




- The day before it was heavy ra
- In the early morning, the slow


- After the sunrise, we found the landed capsule and parachute from helicopter.
- After safety treatment, we brought back the capsule to Japan without being contaminated by Earth air.

©JAXA

# 1. Hayabusa2 mission: Returned sample

- 5.4 g of asteroid sample with deep black was found in the capsule.
- Ryugu sample database was open to public, and the sample was distributed to the researchers around the world through the AO.
- Organic matter, amino acid and water were detected in the grain.
- 40% of the sample was stored for the future and 10% was exchanged with NASA for Bennu sample brought back by OSIRIS-REx.

© JAXA

- Bennu: C-type asteroid
- We are very looking forward to the analysis of Bennu sample.
- Exciting results are expected in the Ryugu-Bennu integrated science.

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# 2. The S&MA activity of Hayabusa2

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In fact, the S&MA activity of Hayabua2 was very usual.

Hayabusa2 followed Hayabusa.

Initial phase:

- Lessons Learned which included hundreds of notice and improvement proposal from Hayabusa.
- The “heavy” experience of Hayabusa was large advantage for Hayabusa2.
- carefully examined and evaluated one by one to see if it was necessary to adopt for Hayabusa2.
- As a results, for example,
  - Improved the redundancy : RW, RCS, AOCP, heater
  - Improved the durability : IES
  - Improved the procedure : rover release, projectile firing

# 2. The S&MA activity of Hayabusa2

Design phase:

- FMEA (Failure Mode and Effects Analysis) was applied for risk analysis
- Virtual FTA (Fail tree analysis) was applied to list up possible non-conformances and to check the countermeasure procedure.

Manufacturing phase:

- MIP (Mandatory Inspection Point) was carried out for the quality inspection.

Test and inspection phase:

- FTA (Fault Tree Analysis) was applied to investigate the occurred non-conformance.

# 2. The S&MA activity of Hayabusa2

- Space mission = Spacecraft + Operation
- In particular, the deep space exploration requires flexible operation.
- “The success” in space mission needs not only “high quality hardware & software” but also “skilled operation team”.
- “Team building” is additionally very important element for mission assurance.


©AFP

Space mission and Formular 1 have similarities.
Ayrton Senna won the championship by ...

# 2. The S&MA activity of Hayabusa2

- Activity for the “team building” that we applied for the Hayabusa2.

1） Sharing the priority and the approach for the “goal”

- Definite success criteria. The goal is very clear for the team.
- Operation team = Space agency + Manufacturing company + University and Institute.
- Each often have different priorities and approach to the goal.

# 2. The S&MA activity of Hayabusa2

- Activity for the “team building” that we applied for the Hayabusa2.

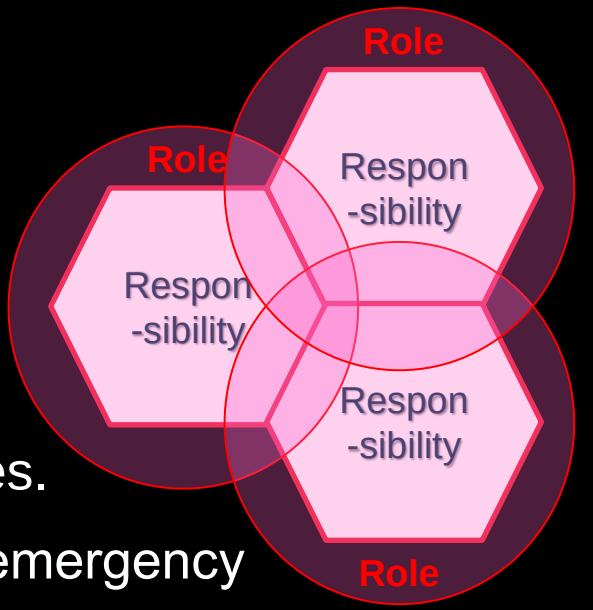
1） Sharing the priority and the approach for the “goal”

- Some slogans to align the philosophy how to reach the goal.
- For example,
  - “All hidden non-conformance should be found before launch, should not be brought into space”
    - We ordinary do not prefer non-conformance in the inspection or test because of the impact.
      But certain non-conformance should exist no matter what.
      The impact of a non-conformance in orbit would be more serious.
      We encourage to find out as many non-conformance as possible before launch “with smile”.
  - “All operation must be tested on ground prior to execution in orbit (no test, no execution)”
    - Some of the trouble in Hayabusa have been caused by using the procedures without enough preparation. This is one of the important lessons learned from Hayabusa.

# 2. The S&MA activity of Hayabusa2

- Activity for the “team building”

2）Sharing the responsibilities and the roles with each other.




- Responsibility: we made responsibility to clarified without gaps in the team.
- Roles: we tried to make roles covering wider than responsibility.
  - For the overlapped area, both could make cross-check to prevent mistakes.
  - And it made increased the flexibility to allow “position change” in case of emergency and increased the team cooperation.

- We treated the team building as one of the important activity of mission assurance.
- These activities do not guarantee success, but we would not be successful without these activities.

# 2. The S&MA activity of Hayabusa2

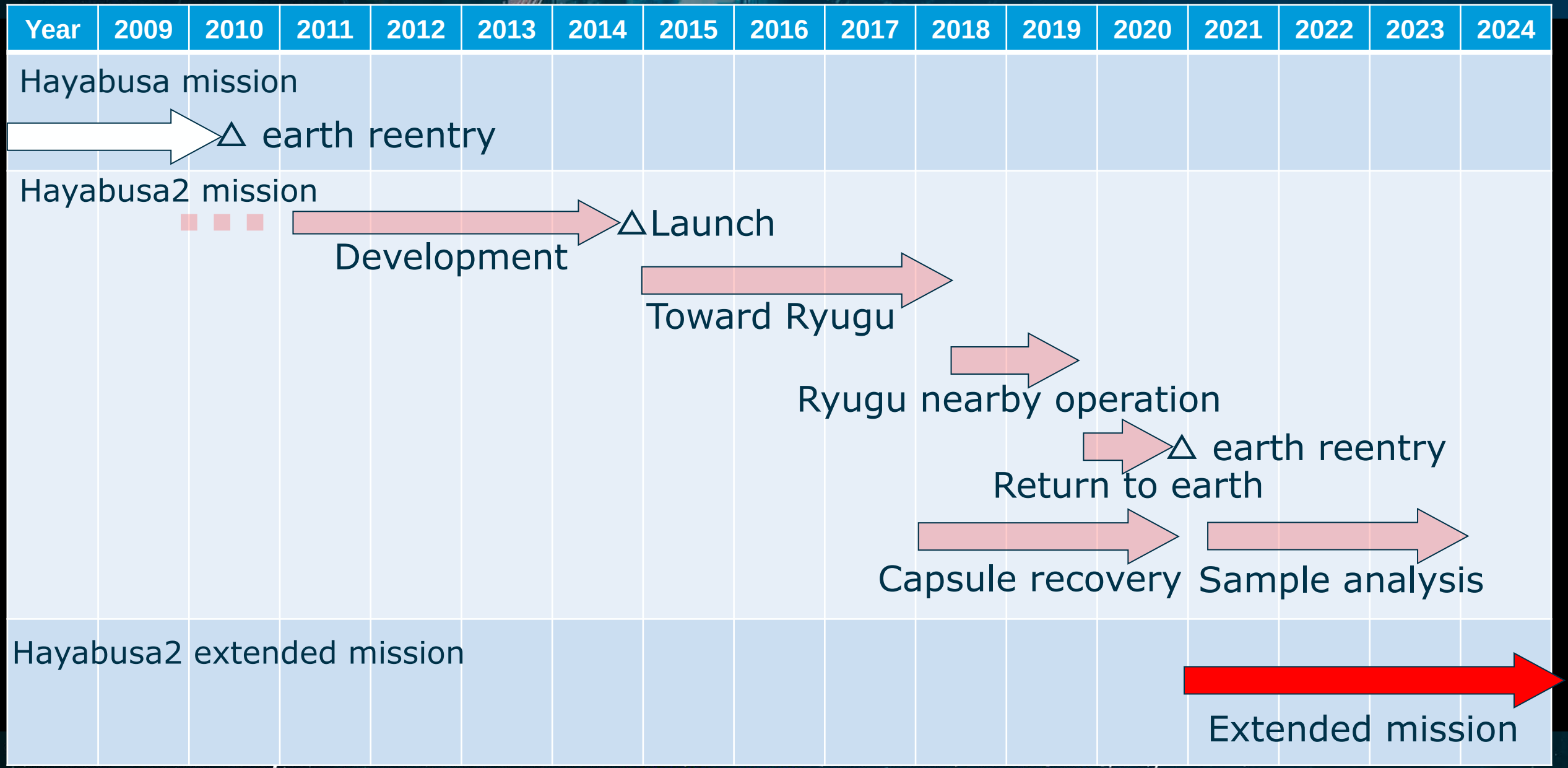
Summary

- As we unfortunately know, It's difficult to serialize deep space mission.
- But Hayabusa2 had fortunately large advantage that we could refer the heavy experiences and the lessons learned from the Hayabusa. It greatly contributed to the success of Hayabusa2.

- In addition to usual S&MA activities, the following “team building” were carried out as part of SMA activities.
  - Sharing the priority and the approach for the “goal”.
  - Sharing the responsibilities and the roles with each other.
- It improved the team skills and greatly increased the possibility of success.
- After returning to earth, we made lessons learned of Hayabusa2 which finally includes over 1000 of item. We hope that it will be useful for the future mission.

# 3. Hayabusa2 Extended mission

# 3. Hayabusa2 Extended mission: Chronology



# 3. Hayabusa2 Extended mission

- The Hayabusa2 returned to earth and passed by without any hardware trouble and with a certain amount of fuel.
- Although there is a risk that the spacecraft have already exceeded its design life, it would be possible to carry out new missions without development and launch.

Selection of the target

- We selected an asteroid “1998 KY26” that can be reached by using remaining fuel and the planetary swing-by technique.
- In this mission, we have “bonus” that we can also fly-by additional asteroid “2001 CC21” on the way to target asteroid “1998 KY26”.

# 3. Hayabusa2 Extended mission:

Chronology

- It takes a very long time to transfer into an orbit exploring another asteroid.

| Year | Event |
|---|---|
| 2021～2026 | Cruising phase |
| July 2026 | 2001 CC21 flyby |
| Dec. 2027 | Earth swing-by (1) |
| June 2028 | Earth swing-by (2) |
| July 2031 | 1998 KY26 Rendezvous |

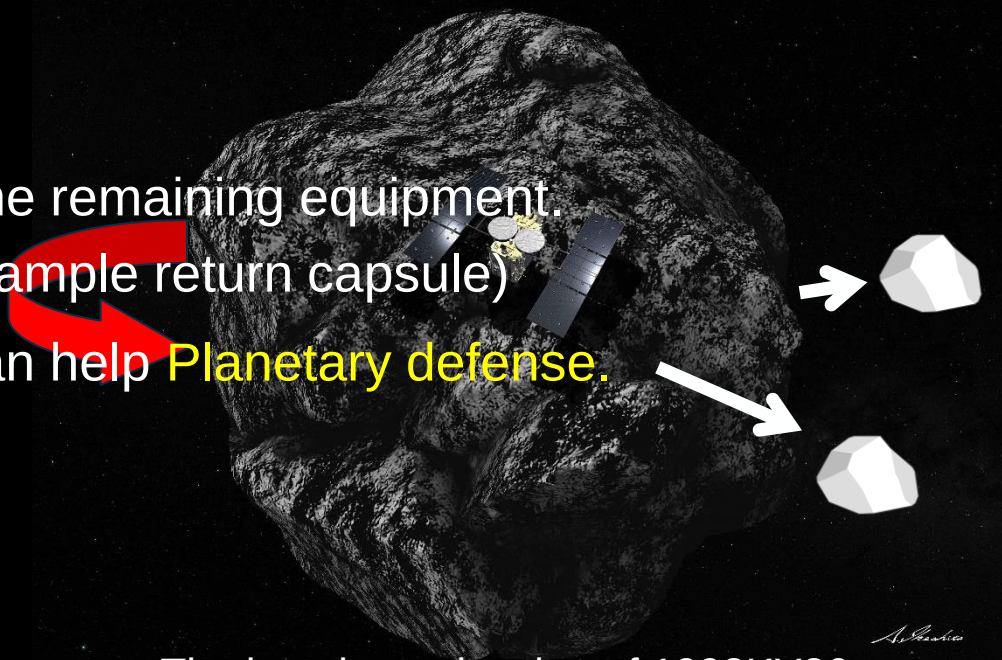
# 3. Hayabusa2 Extended mission

- Target asteroid “1998 KY26” is very interesting.
  - Estimated diameter: about 30[m]
  - Observed rotation period ：10[min]
- The calculated centrifugal force is greater than its gravity. A stone cannot stand still on the surface.
- It can predict that the asteroid might not be covered with regolith nor rocks, might be single rock.

Mission design

- We are considering missions design that can be done with the remaining equipment.
  (Sampler projectile, visible camera, thermal IR camera, No sample return capsule)
- The physical properties of such small fast rotated asteroid can help Planetary defense.

Stay tuned for the arrival !



The imaginary drawing of 1998KY26

# *To Be Continued*