Asteroid explorer, Hayabusa2, reporter briefing

October 28, 2019

JAXA Hayabusa2 Project

Topics

Regarding Hayabusa2,

- Results from the target marker separation operation
- Result from the MINERVA-II2（Rover2） separation operation

※ Rover2 (MINERVA-II2) will also be described by Tohoku University, representing the university consortium

Contents

Overview of Hayabusa2

Objective

We will explore and sample the C-type asteroid Ryugu, which is a more primitive type than the S-type asteroid Itokawa that Hayabusa explored, and elucidate interactions between minerals, water, and organic matter in the primitive solar system. By doing so, we will learn about the origin and evolution of Earth, the oceans, and life, and maintain and develop the technologies for deep-space return exploration (as demonstrated with Hayabusa), a field in which Japan leads the world.

Expected results and effects

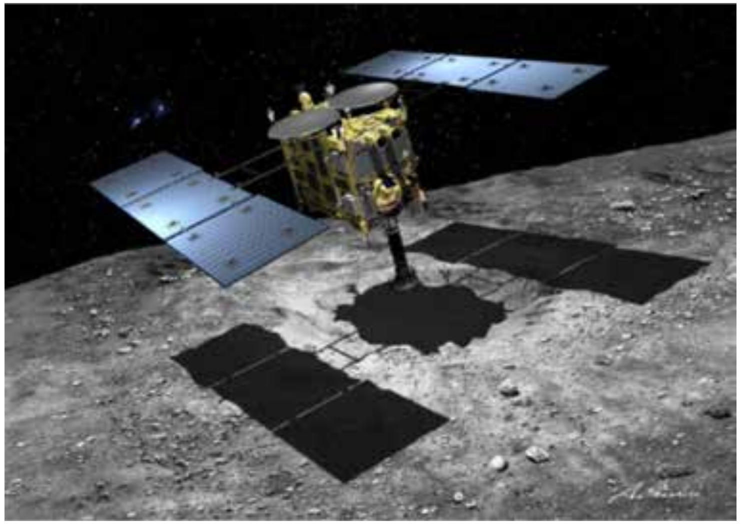
- By exploring a C-type asteroid, which is rich in water and organic materials, we will clarify interactions between the building blocks of Earth and the evolution of its oceans and life, thereby developing solar system science.
- Japan will further its worldwide lead in this field by taking on the new challenge of obtaining samples from a crater produced by an impacting device.
- We will establish stable technologies for return exploration of solar-system bodies.

Features:

- World’s first sample return mission to a C-type asteroid.
- World’s first attempt at a rendezvous with an asteroid and performance of observation before and after projectile impact from an impactor.
- Comparison with results from Hayabusa will allow deeper understanding of the distribution, origins, and evolution of materials in the solar system.

International positioning:

- Japan is a leader in the field of primitive body exploration, and visiting a type-C asteroid marks a new accomplishment.
- This mission builds on the originality and successes of the Hayabusa mission. In addition to developing planetary science and solar system exploration technologies in Japan, this mission develops new frontiers in exploration of primitive heavenly bodies.
- NASA too is conducting an asteroid sample return mission, OSIRIS-REx (launch: 2016; asteroid arrival: 2018; Earth return: 2023). We will exchange samples and otherwise promote scientific exchange, and expect further scientific findings through comparison and investigation of the results from both missions.



(Illustration: Akihiro Ikeshita)

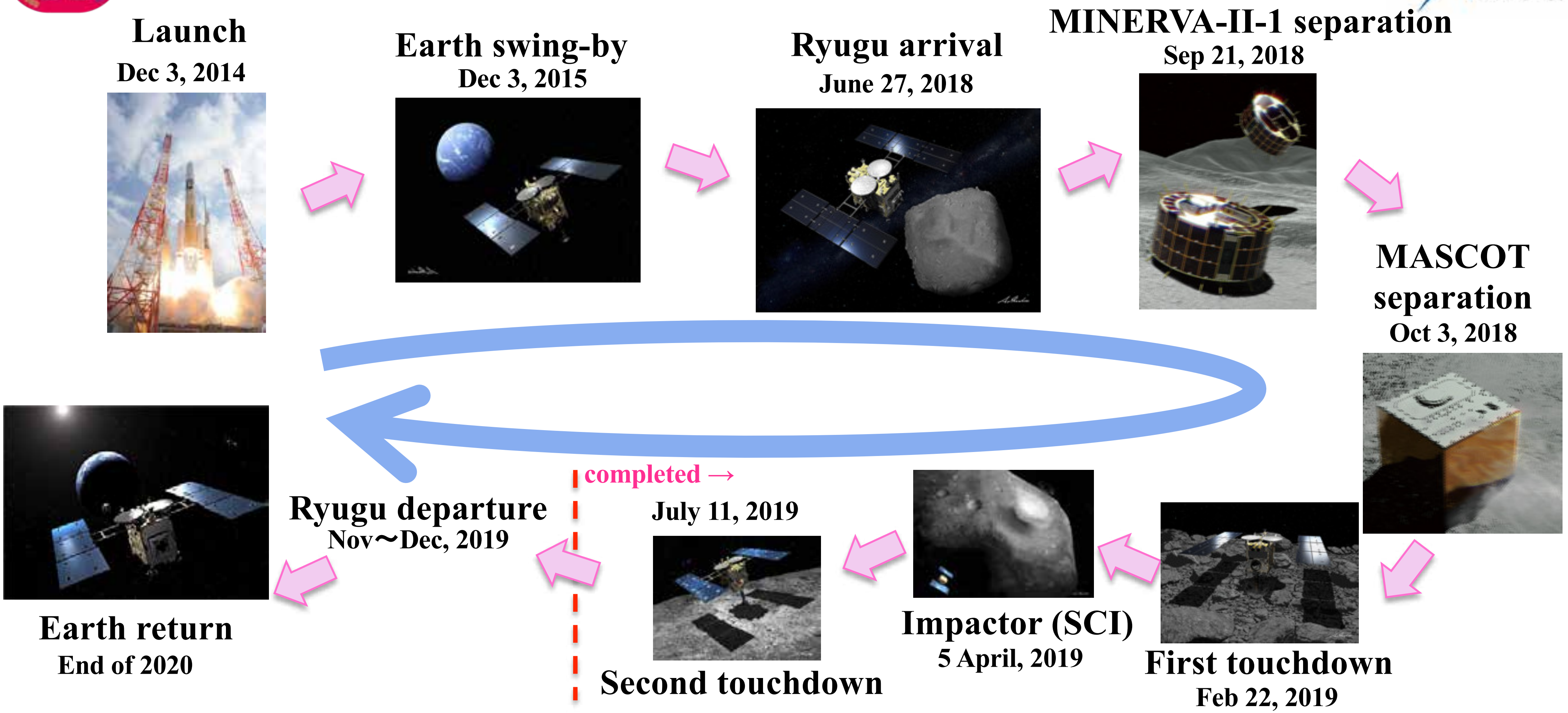
Hayabusa 2 primary specifications

Mass	Approx. 609 kg
Launch	3 Dec 2014
Mission	Asteroid return
Arrival	27 June 2018
Earth return	2020
Stay at asteroid	Approx. 18 months
Target body	Near-Earth asteroid Ryugu

Primary instruments

Sampling mechanism, re-entry capsule, optical cameras, laser range-finder, scientific observation equipment (near-infrared, thermal infrared), impactor, miniature rovers.

Mission flow



Launch
Dec 3, 2014

Earth swing-by
Dec 3, 2015

Ryugu arrival
June 27, 2018

MINERVA-II-1 separation
Sep 21, 2018

MASCOT separation
Oct 3, 2018

First touchdown
Feb 22, 2019

Impactor (SCI)
5 April, 2019

Second touchdown
July 11, 2019

completed →

Ryugu departure
Nov〜Dec, 2019

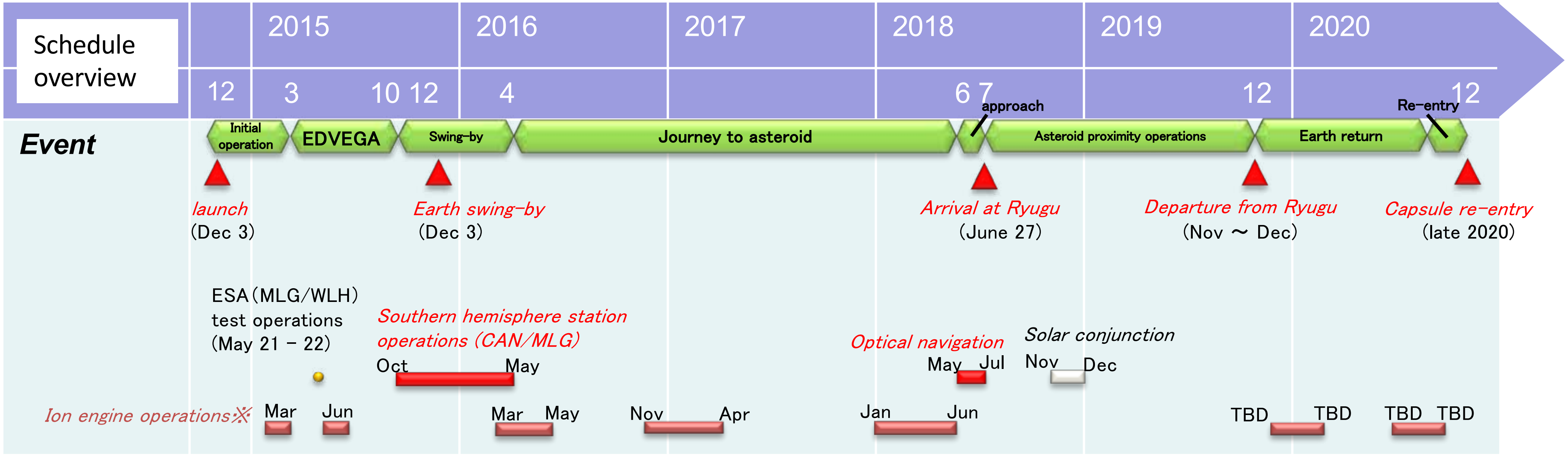
Earth return
End of 2020

(image credit: illustrations including spacecraft by Akihiro Ikeshita, others by JAXA)

1. Current project status & schedule overview

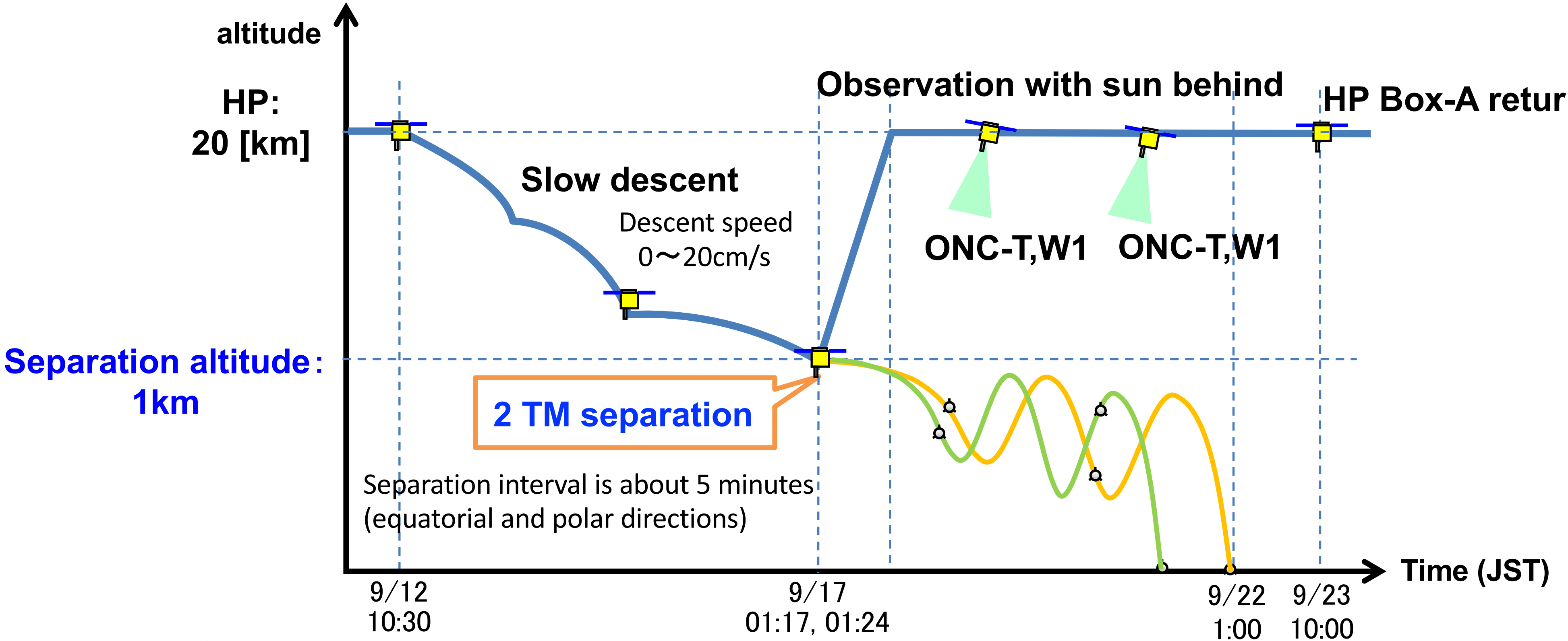
Current status：

- The separation operation for MINERVA-II2 (Rover 2) was conducted from September 28 to October 3. The separation was able to occur as scheduled on October 3 at 00:57 JST (on-board time).
- The spacecraft then remained at an altitude of about 8km and observed Rover2, before returning to the home position on October 15.
- BOX-C operation will be conducted between October 19 to October 30. The minimum altitude will be about 4km between October 24 〜 26. Data will be acquired using onboard science instruments.



2. Target marker separation operation results

Target marker separation operation sequence results



altitude

HP:
20 [km]

Separation altitude: 1km

Slow descent

Descent speed
0～20cm/s

2 TM separation

Separation interval is about 5 minutes
(equatorial and polar directions)

Observation with sun behind

HP Box-A return

ONC-T,W1

ONC-T,W1

Time (JST)

9/12
10:30

9/17
01:17, 01:24

9/22
1:00

9/23
10:00

（Image credit：JAXA）

2. Target marker separation operation results

Point 1: Target marker (TM) separation operation

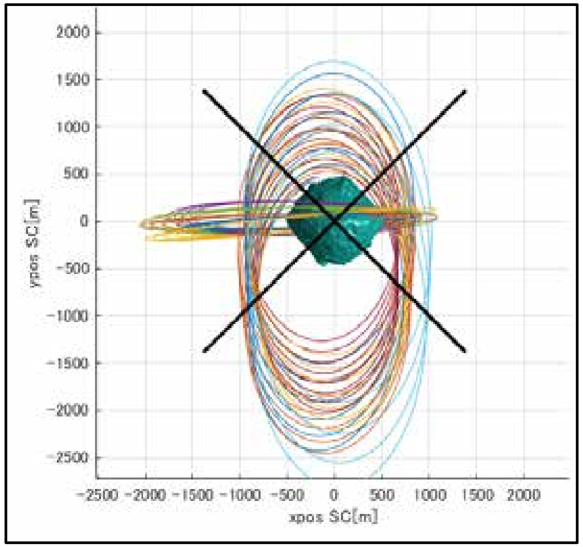
① TM orbit injection

- Polar orbit : a stable orbit with good observability
- Equatorial orbit : an orbit with a higher contribution to the gravity estimate.

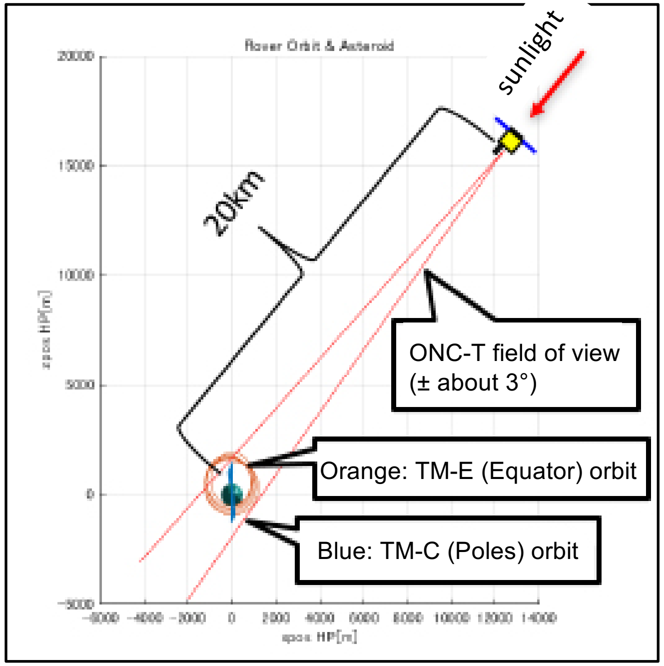
Injection to completely different orbits

② TM imaging method and observation location / attitude

- Image from a distance (20km) where the trajectory of the TM can fit entirely within view.
- To utalize the TM retroreflectivity, the bright TM was imaged when the Sun was behind the spacecraft.
- Image capture interval set to 30 minutes.



TM orbit seen from the spacecraft（example of designed trajectory）



Relationship between TM orbit and spacecraft for TM observation (design time)

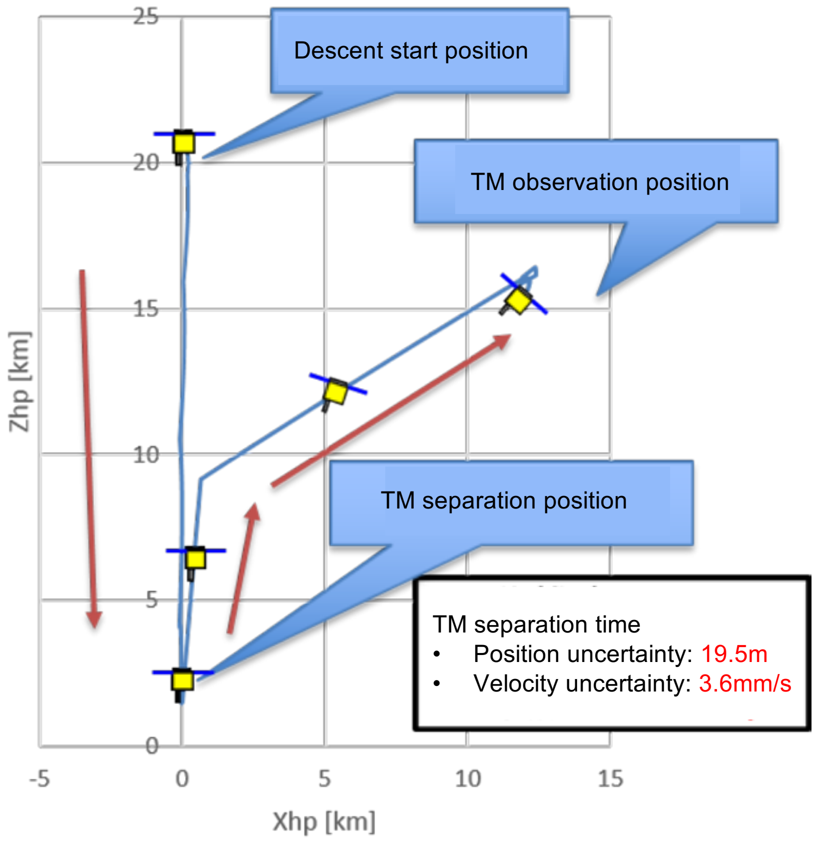
（Image credit：JAXA）

2. Target marker separation operation results

Point 2: Target marker (TM) separation operation

③ Execution of slow descent / ascent / hovering with "natural motion in high accuracy"

- 1 year of exploration has allowed skilled control of the spacecraft around the asteroid.
- Spacecraft was lowered along a natural orbit trajectory.



TM separation time
- Position uncertainty: 19.5m
- Velocity uncertainty: 3.6mm/s

◆ Control interval : This time, once a day ⇔ normally need once every 10 minutes

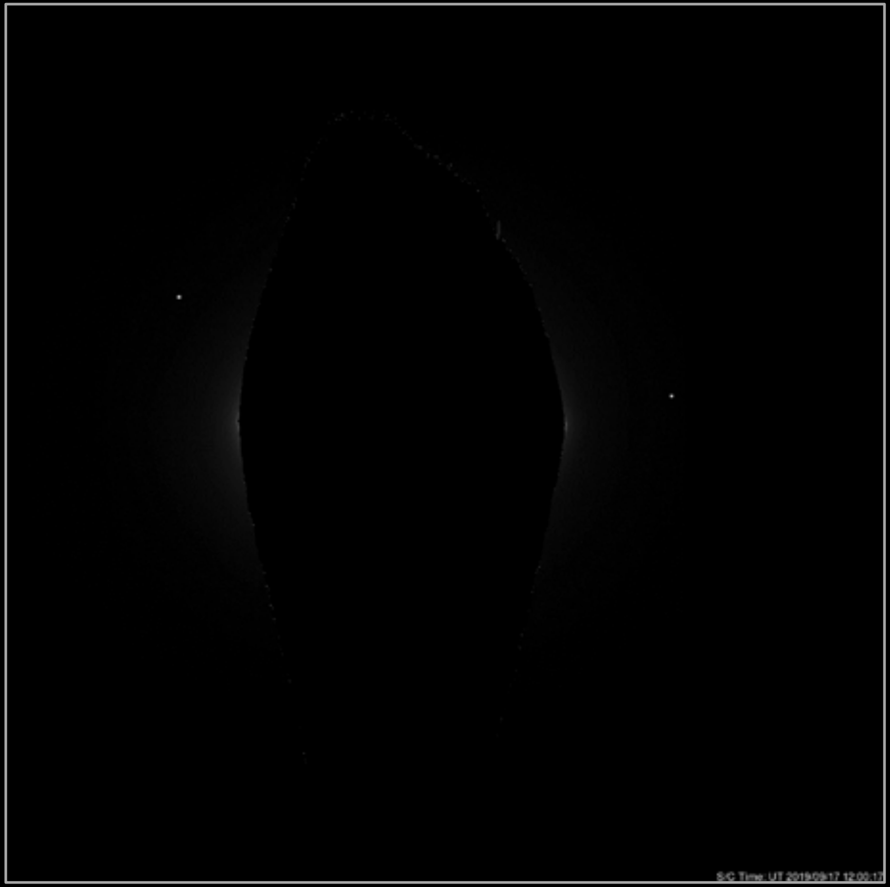
（image credit : JAXA）

2. Target marker separation operation results

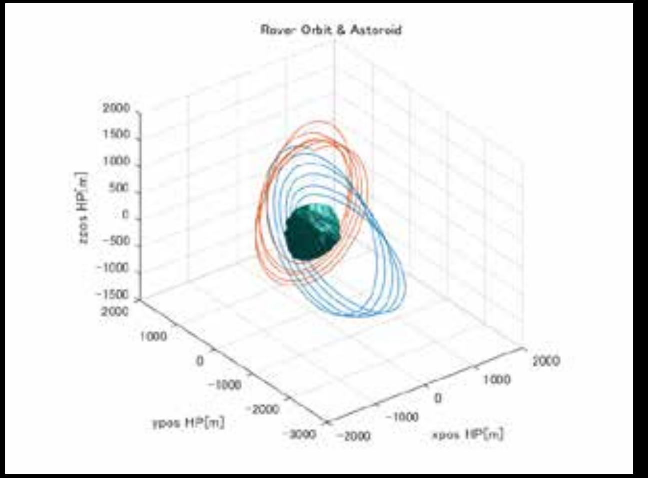
TM-E (equatorial orbit) and TM-C (polar orbit) (ONC-T) orbiting the asteroid

First
release

(animation)



Estimated trajectory

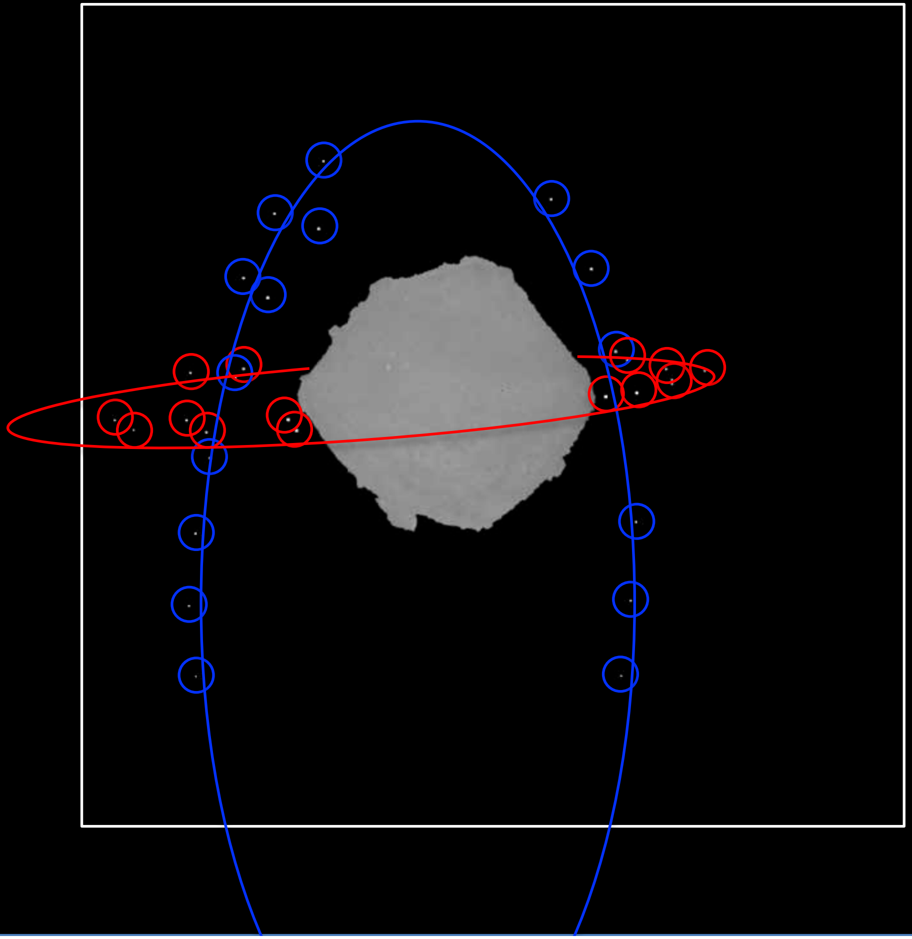


(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

2. Target marker separation operation results

TM-E (equatorial orbit) and TM-C (polar orbit) (ONC-T) orbiting the asteroid

First release



○ TM-E（equatorial）

○ TM-C（polar）

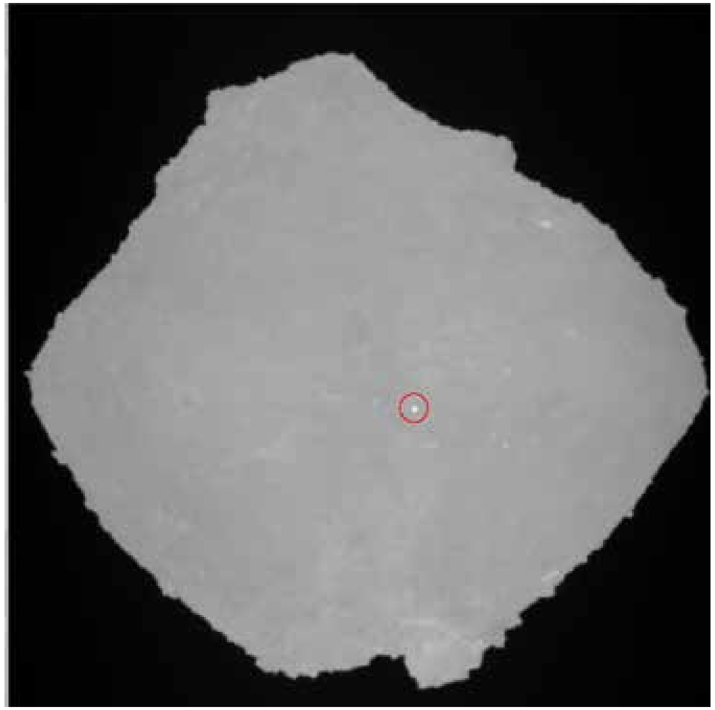
(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

2. Target marker separation operation results

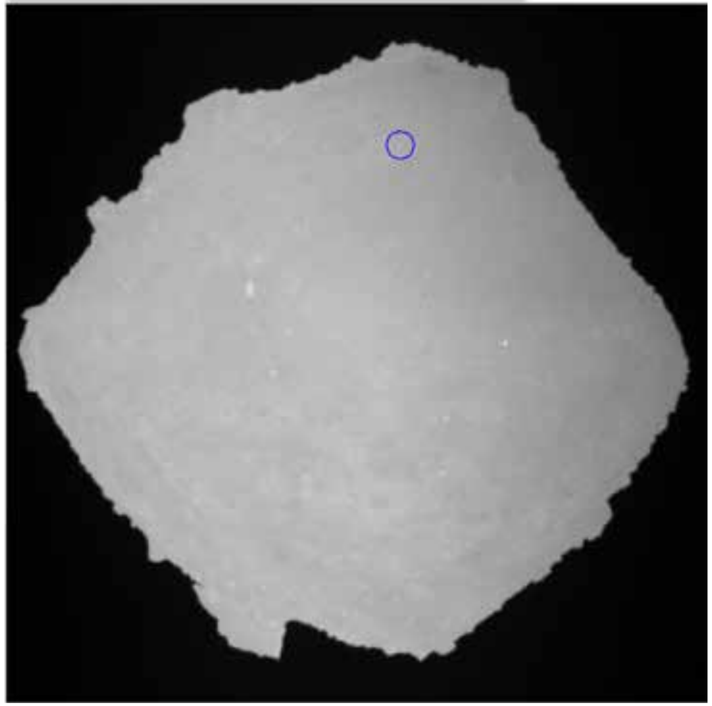
First release

Identification of where TM-E (equatorial orbit) and TM-C (polar orbit) landed on asteroid Ryugu after orbit.

TM-E（Equatorial orbit）

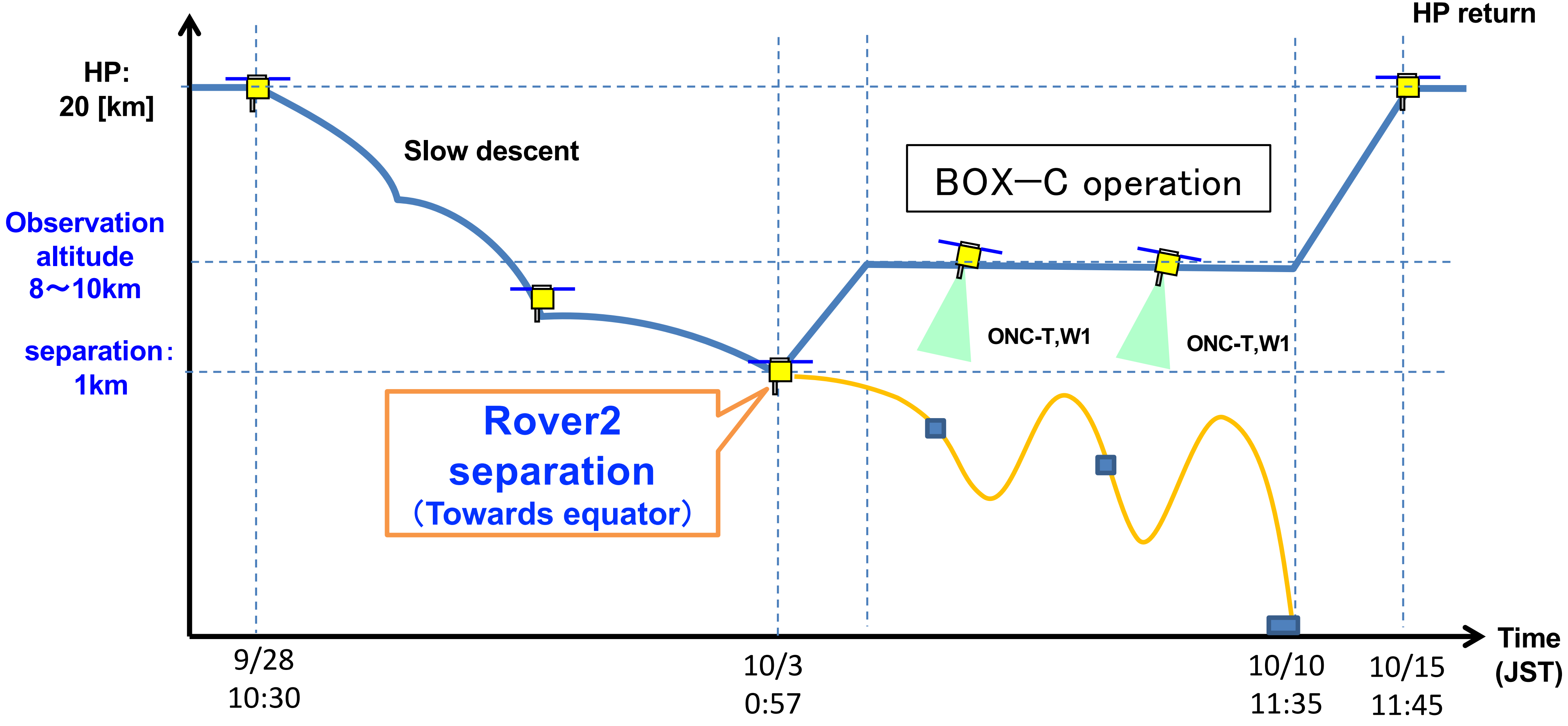


TM-C（Polar orbit）



(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

3. MINERVA-II2 (Rover2) separation operation results



3. MINERVA-II2 (Rover2) separation operation results

Point of separation operation for Rover2

① Design of orbit injection condition for Rover2

- Unstable trajectory that can reliably land Rover2 on the asteroid.

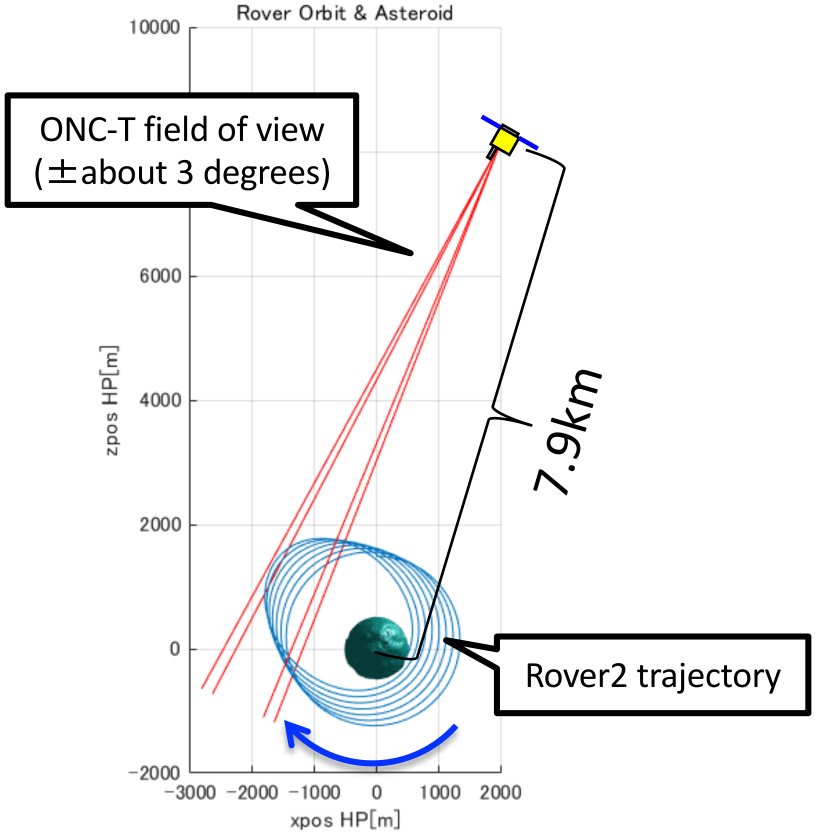
② Rover2 imaging method and observation position / attitude

- As the rover is darker than the TM, images were taken from a low altitude with a long exposure time (about 3 minutes).
- To capture the image of the rover passing through the field of view, imaging was performed at frequent 10 minutes internals.
- The rover was found in a large number of images.

③ Execution of slow descent / ascent / hovering with "natural motion in high accuracy"

- The team used the experience gained from the TM orbits.

Relationship between the rover orbit and spacecraft for observation (design time)



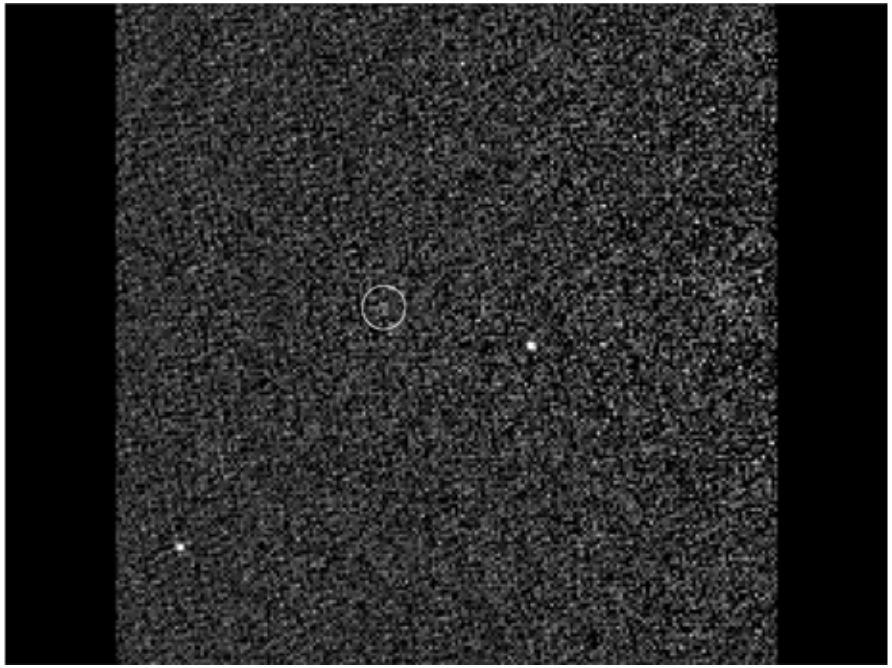
（Image credit：JAXA）

3. MINERVA-II2 (Rover2) separation operation results

First release

(animation)

Rover orbit taken with the ONC−W1 (30 minute intervals)



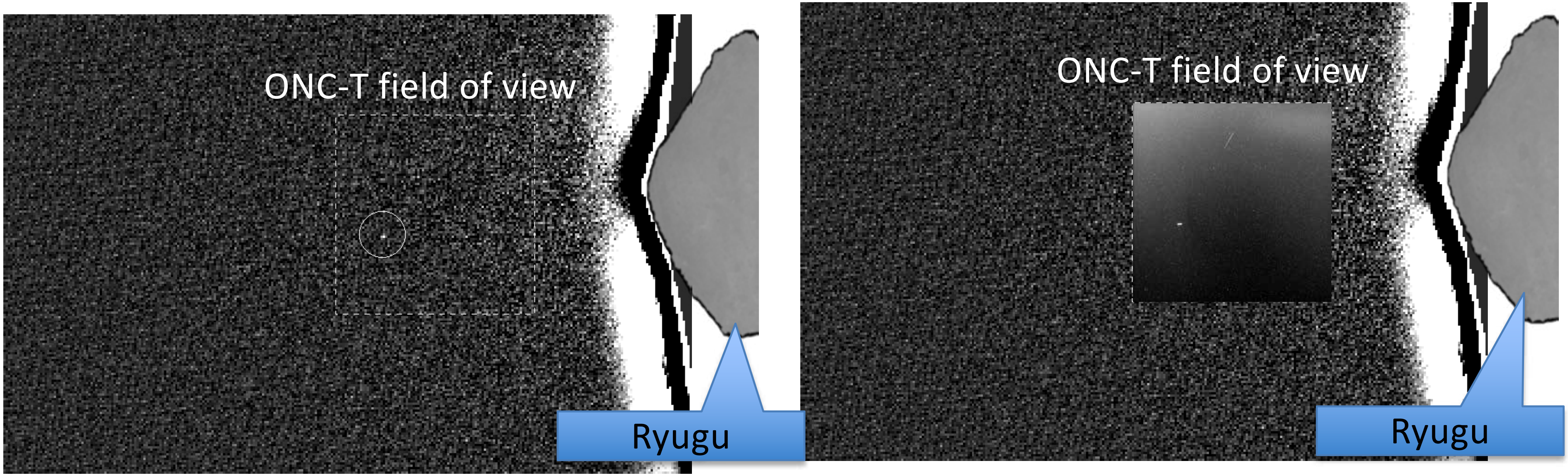
Rover orbit taken with the ONC—T (10 minute intervals)

(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

3. MINERVA-II2 (Rover2) separation operation results

First release

Rover2 captured with both the ONC-T and ONC-W1
(two images taken at almost the same time)



(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

3. MINERVA-II2 (Rover2) separation operation results

Estimated trajectory

- From orbit estimation after the operation, the rover reached the asteroid surface about 1 day after separation (about 1.25 orbits)

ONC imaging

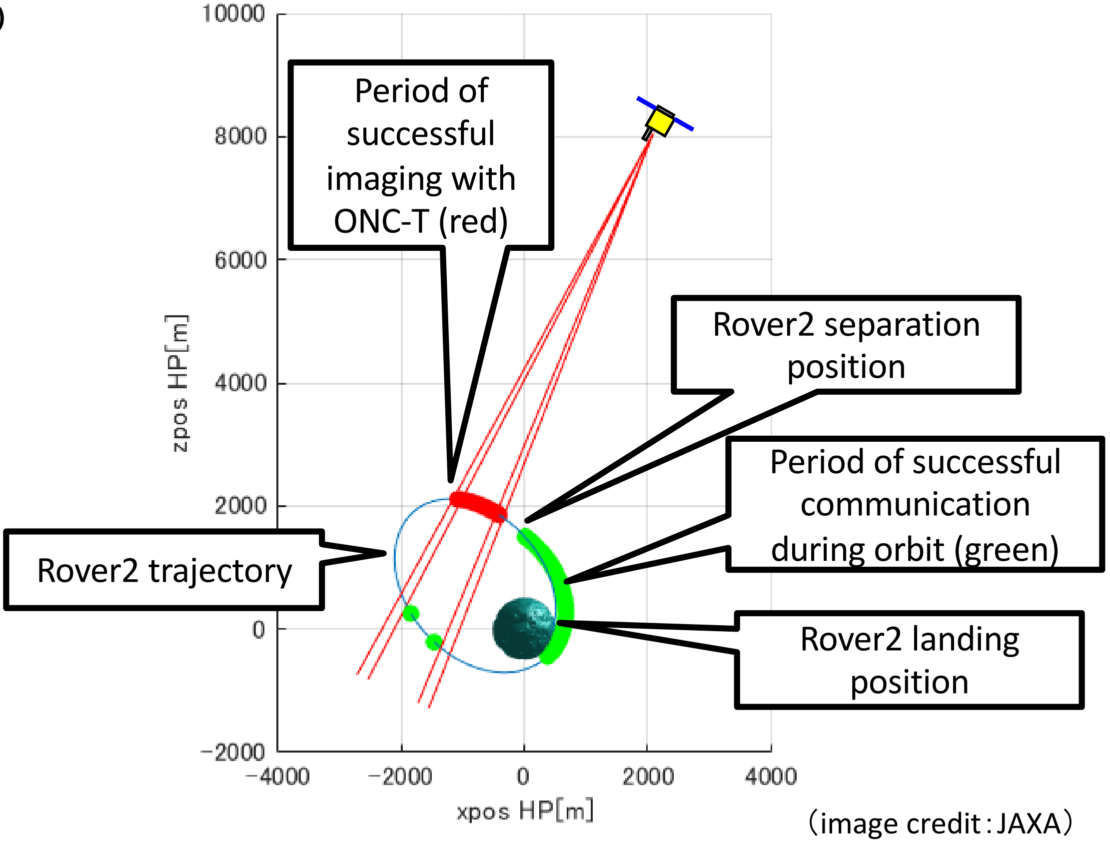
- Successful observation during orbiting in addition to imaging during separation.
- Confirmation of rover in 15 images using ONC-W1
- Confirmation of rover in 14 images with ONC-T

Communication

- Secure communication link with Rover2 even after separation.
- Communication was possible even after the periods of shadow passing.
- Communication remains possible after landing.
- Detecting the ranging signal with Rover2.

For details, see the report from the university consortium.

Rover2 estimated trajectory and ONC-T imaging / communication link (during orbit) period



（image credit：JAXA）

Results obtained from the separation operations

- The need for a rehearsal operation was introduced during the study for the Rover2 operation. This led to the idea of using the TM separation and that results could be maximised by combining the two operations.
- This was the world's first successful experiment of multiple artificial satellites into the orbit around a small celestial body.
- The operations also achieved the world's smallest artificial satellite (TM) around an extraterrestrial body.
- Successfully acquired data for gravity field estimating by multiple artificial orbits using different observation data types (optical observation, radiowaves).
- A new gravity estimation method was put into practice and the operation was completed.

Background and appreciation of executions of the orbit operation for the target marker and the MINERVA-II2 rover.

Hayabusa2 Project Manager Yuichi Tsuda

- **The idea of orbiting an object around an asteroid** was born at the beginning of the development for Hayabusa2 (around 2012), during a discussing with the Hayabusa2 Project Astrodynamics Science Team. Since the time schedule of development was tight, we could not inculude this idea into the plans for Hayabusa2, but the idea continued to be developed as a topic of research (Astrodyanmics).
- By combining the orbit of the MINERVA-II2 rover with that for the target marker that had already been studied in advance, a new role for the MINERVA-II2 rover was fashioned that could **improve the results for the gravity science**. Professor Daniel Scheeres and his group at the University of Colorado, Boulder and Professor Junichiro Kawaguchi at ISAS were deeply involved in this work. The university consortium were also actively involved in the decision to make this major change to how this rover would be used.
- We were very fortunate to receive radiowaves from MINERVA-II2 after separation, which included a ranging signal. By combining the radio signal and the observations from Hayabusa2 of the two target markers and MINERVA-II2 in orbit, we established a new gravitational field measurement method that has never previously been used. This is also a **world first** for '**the smallest-object constellation around a small celestial body**'!
- We were able to create the new effective plan to use the MINERVA-II2 Rover which had some problems with great teamwork. As a result, the MINERVA-II2 Rover worked well in its new role. I am very proud of these things, because they symbolize the mission of Hayabusa2. For all those who helped **realize such flexible and innovative science with Hayabusa2**, including the Hayabusa2 Mission team, Astrodynamics team, university consortium team including Tohoku University and the University of Colorado Boulder, I thank you deeply.

4. Name for the orbiting target markers

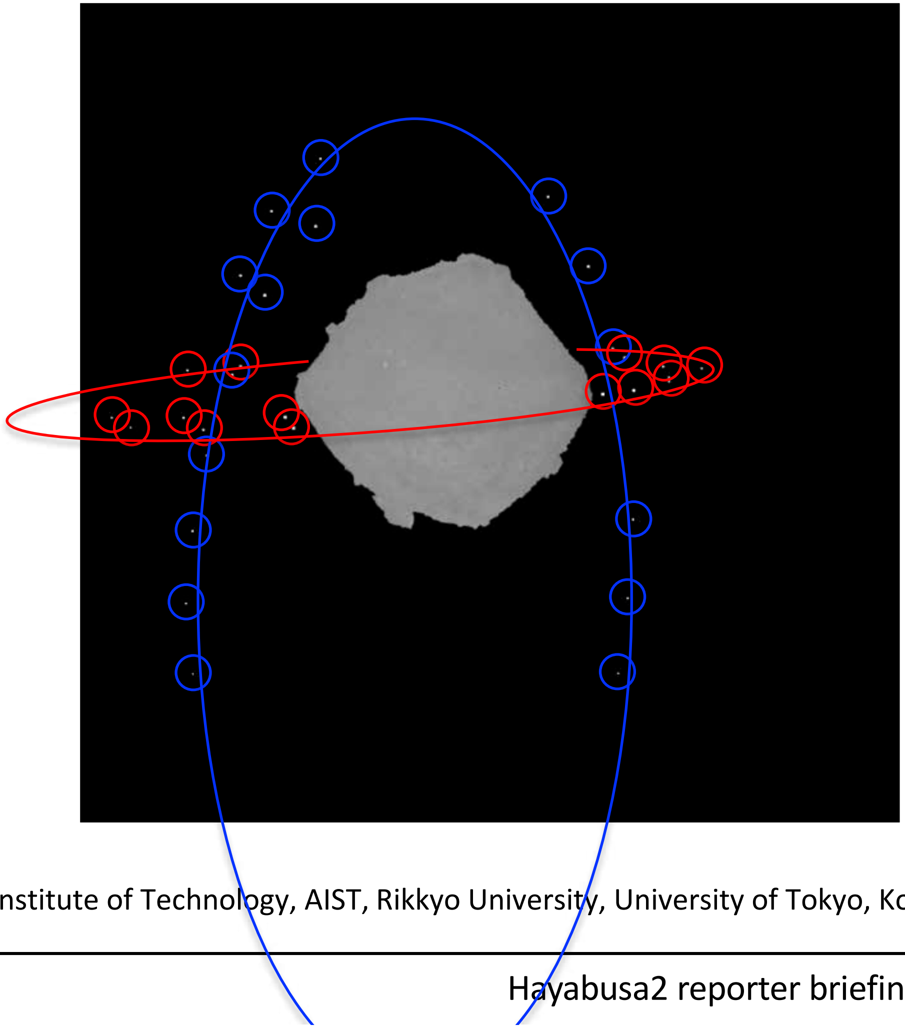
We decided to give the target markers used for the orbital operation the following names:

- TM-C：Sputnik (Спутник)
- TM-E：Explorer

■Reason

- These two target markers are the first artificial satellites to orbit around asteroid Ryugu. The first satellite series on Earth were named Sputnik and Explorer.
- In Russian, 'Sputnick' begins with a 'C', so this name was chosen for TM-C, while 'Explorer' with an 'E' went to TM-E.
- Sputnik 1 has a larger orbit inclination angle (inclination with respect to the equatorial plane) and is closer to the TM-C orbit.

4. Name for the orbiting target markers



○ TM-E (red orbit)

Explorer

○ TM-C (blue)

Sputnik

(Image credit: JAXA, Chiba Institute of Technology, AIST, Rikkyo University, University of Tokyo, Kochi University, Nagoya University, Meiji University, University of Aizu)

5. Future plans

■Operation schedule

October 19-30	BOX-C operation
November ～ December	Departure from Ryugu

■Press briefings

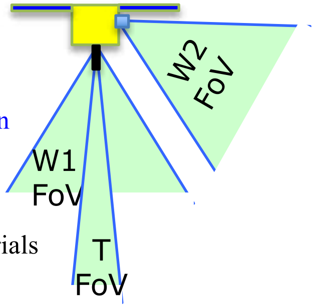
November 12 afternoon	Press conference @Sagamihara campus

Reference

Optical navigation camera (ONC)

ONC：Optical Navigation Camera

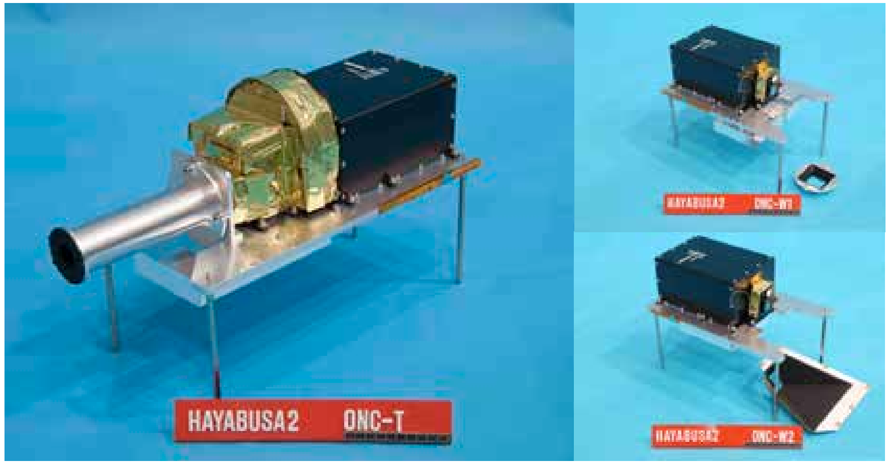
Objective: Images fixed stars and the target asteroid for spacecraft guidance and scientific measurements



Scientific measurements：

- Shape and motion of the asteroid:
  Diameter, volume, direction of inertial principal axis, nutation
- Global observations of surface topography
  Craters, structural topography, rubble, regolith distribution
- Global observations of spectroscopic properties of surface materials
  Hydrous mineral distribution, distribution of organic matter, degree of space weathering
- High-resolution imaging near the sampling point
  Size, form, degree of bonding, and heterogeneity of surface particles; observation of sampler projectiles and surface markings

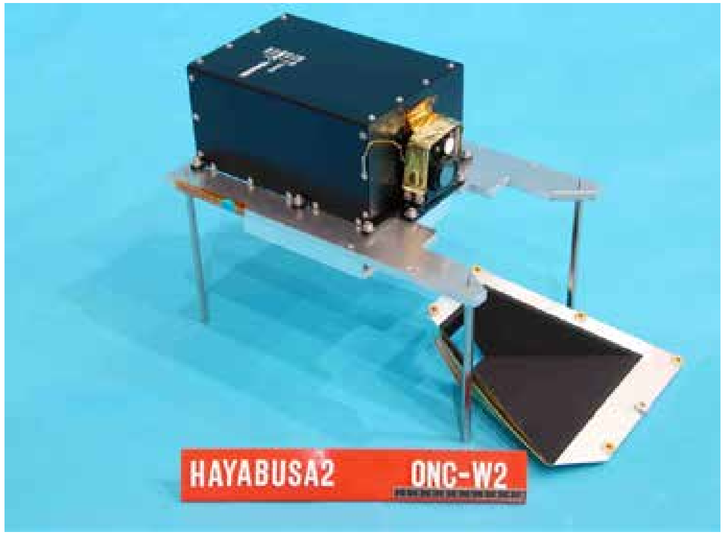
- Elucidation of features of target asteroid
  - Distribution of hydrated minerals and organic matter, space weathering, boulders
- Sampling site selection
  - Basic information on where to collect asteroid samples
- Ascertaining sample state
  - High-resolution imaging of sampling sites



(© JAXA)

	ONC-T	ONC-W1	ONC-W2
Detector	2D Si-CCD (1024 × 1024 px)		
Viewing direction	Downward (telephoto)	Downward (wide-angle)	Sideward (wide-angle)
Viewing angle	6.35° × 6.35°	65.24° × 65.24°	
Focal length	100 m–∞	1 m–∞	
Spatial resolution	1 m/px @ 10-km alt. 1 cm/px @100-m alt.	10 m/px @10-km alt. 1 mm/px @1-m alt.	
Observation wavelength	390, 480, 550, 700, 860, 950, 589.5 nm, and wide	485–655 nm	

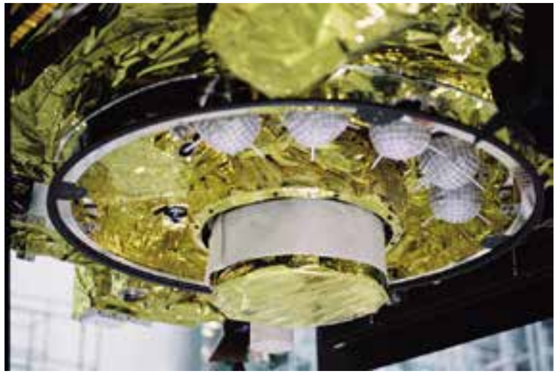
ONC-W2 mounting position

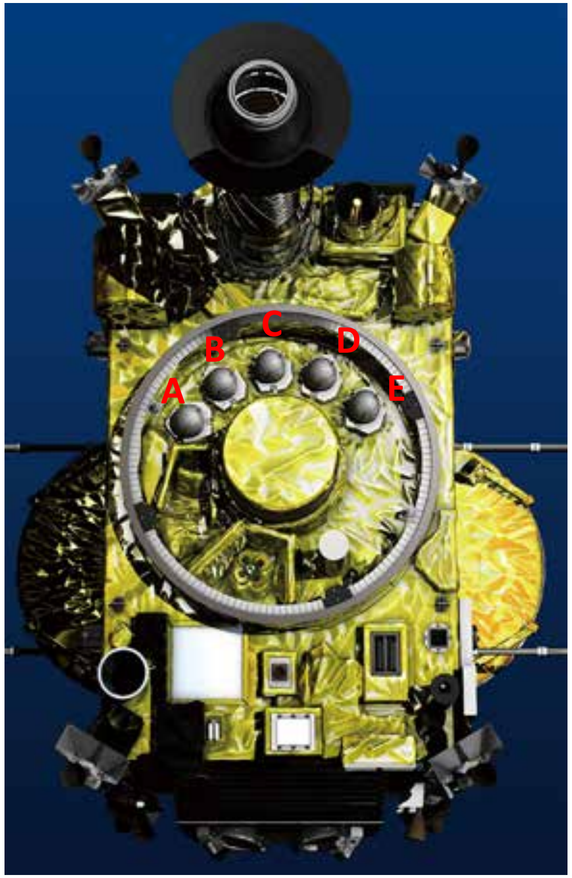


- Mounted on the side. Diagonal-downwards imaging possible.
    - Earth imaging during swing-by
    - MASCOT separation imaging
    - SCI crater search operation on Ryugu

（image credit：JAXA）

Target marker



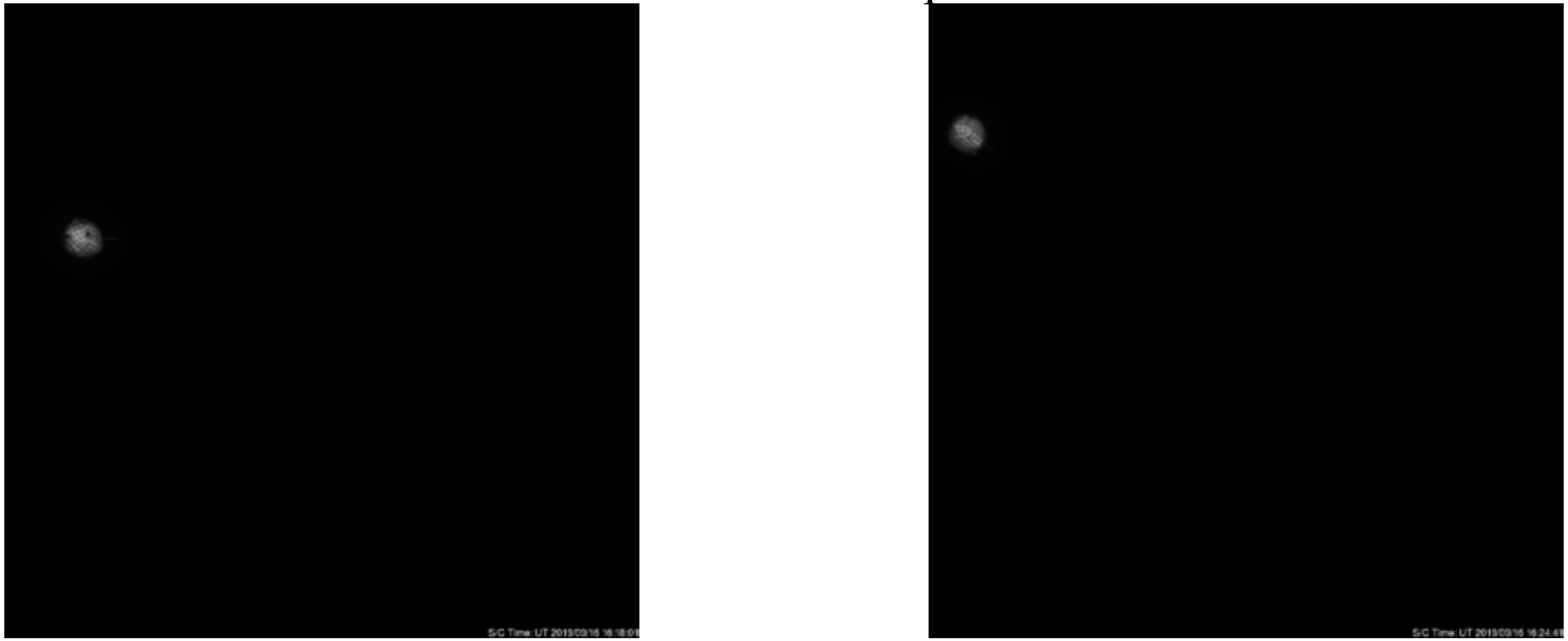


- Body (ball) size: about 10cm diameter
- Retroreflective film on the surface
- 4 bar rolling prevention
- Many polyimide small balls inside
- Separation order：B→A→E→C→D
- 2018/10/25: B dropped
- 2019/05/30: A dropped
- 2019/09/17 E and C dropped

（Image credit：JAXA）

Target marker separation

（animation）



Target marker E separation
（separation time：2019/9/17 01:17 JST）

Target marker C separation
（separation time：2019/9/17 01:24 JST）

Animation of the target markers taken from the spacecraft. Images captured at 4s intervals. In the first image, the distance to the target marker is about 1m, and in the final image is is about 9m (the target marker is not dropping, but the spacecraft moves away from the target marker.)

（credit：JAXA、Chiba Institute of Technology、University of Tokyo、Kochi University、Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST.）