Hayabusa2: Successful Touchdown and Scientific Findings for Ryugu

Hayabusa2 Project Team
Yuichi Tsuda, Japan Aerospace Exploration Agency
Sei-ichiro Watanabe, Nagoya University
Ralph E. Milliken, Brown University
Seiji Sugita, University of Tokyo

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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.

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.
Spacecraft Overview

Small lander & rovers

**MASCOT**
- Built by DLR and CNES

**Minerva 2**
- **II-1A**: By the JAXA Minerva-II team
- **II-1B**: By Tohoku Univ. & the Minerva-II Consortium
- **II-2**: By Tohoku Univ. & the Minerva-II Consortium

**Scientific observation equipment**
- **Optical navigation camera, ONC-T**
- **Laser altimeter, LIDAR**
- **Near-infrared spectrometer, NIRS3**
- **Thermal infrared camera, TIR**
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**Minerva-II landers & rovers**
- MASCOT lander
- Minerva-II rovers

**Size**: 1 × 1. 6×1. 25 m (main body)
**Mass**: 609 kg (incl. fuel)

**Deployable camera (DCAM3)**
- X-band mid-gain antenna
- X-band high-gain antenna
- X-band low-gain antenna
- Ka-band high-gain antenna

**Star trackers**

**Near-infrared spectrometer (NIRS3)**

**Re-entry capsule**
- Sampler horn
- Laser altimeter (LIDAR)

**Solar array paddle**
- Deployable camera (DCAM3)
- X-band high-gain antenna
- X-band mid-gain antenna

**Thermal infrared camera** (TIR)

**Optical navigation camera** ONC-T, ONC-W1, ONC-W2

**RCS thrusters**
- Ion engine
- Optical navigation camera
- ONC-T, ONC-W1

**Small carry-on impactor (SCI)**

**Target markers**: × 5
Examine the asteroid by remote sensing observations. Next, release a small lander and rover and also obtain samples from the surface.

After confirming safety, touchdown within the crater and obtain subsurface samples.

Use an impactor to create an artificial crater on the asteroid’s surface.

Illustrations: Akihiro Ikeshita
Ryugu

- 300 million km distant from the Earth (20 min by the speed of light)
- Top shape
- Size ~900m in diameter
- Very dark surface
- Low gravity
- Upright and retrograde rotation
- Numerous boulders (very bumpy!)
Decided Landing Sites and Accomplishments

The three landing targets were decided at the project-wide "Landing Site Selection Decision meeting" held on Aug. 17, 2018.

- **MINIERVA-II-1 Landing Target**
  - Landed on Sep. 21, 2018

- **MASCOT Landing Target**
  - Landed on Oct. 3, 2018

- **Touchdown Target**
  - L08 (Primary)
  - L07, M04 (Backup)

(Image Credit: JAXA/UTokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/Meiji U/U Aizu/AIST)
Within originally selected L08 site, L08-B was targeted for landing practice.

(Image Credit: JAXA/UTokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/Meiji U/U Aizu/AIST)
Strategy Change for Touchdown

Before TM Drop (Original Plan)
- The original design assumes a touchdown accuracy of 50m.
- L08 area (100x100m width) has been selected as the target landing site in the Landing Site Selection Decision meeting on Aug.17, 2018.
- Further observations revealed that even L08 only has safe areas with size less than 10m.
- The project has decided to postpone the original landing planned in October 2018, and add a landing rehearsal operation to deploy the Target Marker (TM) first to precisely evaluate the terrain-relative navigation & guidance performance.

After TM Drop (Modified Plan)
- Based on the result from this TM drop (landing rehearsal) operation, the project defined the landing target L08-E1, which requires a landing with a precision of 3m and with an offset of 4m from the dropped TM.
- The project decided to apply the “pin-point touchdown” method to perform the 3m precision landing.
Landing/Sampling Target (After TM drop)

Location of Target Marker (TM) and landing target L08-E1

Digital Elevation Map and Landing Error (Monte-Carlo) Simulation in Planning Phase

TM: Target Marker

Touchdown safety
- Safe
- Unsafe

(Images credit: JAXA)
Integrated Scientific Activity Toward Touchdown

◆ Laboratory Experiment
Ryugu's stimulant fragmented after firing a high-speed projectile.
※ Ryugu's stimulant is created at the University of Tokyo & TeNQ

◆ In-Situ Observation Data from MINERVA-II, MASCOT and ONC-T/W1

◆ Accurate Terrain Modeling
<10cm accuracy 3 dimensional digital elevation map (DEM) has been created

Achievable Landing Accuracy
Original: 50m
Improved: 2.7m

Sep. 23, 2018, 10:10 JST:
image by MINERVA-II-1B
Autonomous Pin-Point Touchdown Sequence

(Movie credit: JAXA)
Target Marker Tracking Movie (Smoothed)
CAM-H (Sampler Horn Monitor Camera) Movie

Successful imagining before and after touchdown with CAM-H (animation)

- Continuous imaging began from 59 seconds before the final descent and images were taken for 5 minutes and 40 seconds while varying the imaging frequency.

- TD moment captured at 1 fps timing.

- Final altitude is about 117m

(Animation plays at 5x speed)  
(Movie credit: JAXA)
A motion picture taken by Hayabusa2’s nadir-viewing wide-angle optical navigation camera (ONC-W1) soon after the touchdown (TD) from 7:29 am on Feb. 22, 2019 (JST) at altitudes from about 6 to 25m. Individual images were pasted on each other after projected to the perspective from infinity. The motions of surface materials induced by TD are seen. The time between adjacent frames is 2 or 4 seconds; 34 seconds of motion pictures during the ascent are shown here. A variety of moving objects can be found in this motion picture. The shadow that moves from the central part of the frame to lower right is the shadow of Hayabusa2. Many fast-moving black shadows with diffuse boundaries are pebbles just underneath Hayabusa2. They look black because they are flying in the shadow of Hayabusa2. Bright moving objects with sharp boundaries are boulders moving on or near the Ryugu surface. Dark rays that have diffuse boundaries and extend radially from where the Hayabusa2 shadow is seen in the beginning of the motion picture is estimated to be materials ejected from the TD site.

(Image Credit: JAXA/ Meiji U/UTokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/ U Aizu/AIST)
Achieved Landing Accuracy and Sample Point

1m precision landing has been achieved!

Touchdown point

Sampling point

Green circle is the planned touchdown point. The deviation from the circle center to the center of the spacecraft (blue dot) is 1m (Background is from the shape model).

Red circle is where the sampler horn is thought to have touched the surface. Green circle is the planned touchdown site. Background is a real image of Ryugu.
Summary

• Hayabusa2 succeeded in touchdown on Ryugu at Feb. 22, 2019, 07:29:10 (JST).
• The achieved landing accuracy was 1m.
• The sample chamber A (one of three chambers) was closed 4 hrs after TD, and the collected sample has been secured.
• Hayabusa2 will perform a kinetic impact experiment (artificial crater forming) on April 5, leave Ryugu in Nov/Dec 2019, and return to the Earth in Nov/Dec 2020.

The movies presented in this material can be downloaded from: http://www.jaxa.jp/press/kit/hayabusa2/td/