Operation status for the asteroid explorer, Hayabusa2

October 11, 2018

JAXA Hayabusa2 Project

Topics

- MASCOT separation operation report
- Touchdown rehearsals and plans

Contents

０. Hayabusa2 mission summary & outline of mission flow

１. Current status and schedule overview for the project.

２. MASCOT separation operation

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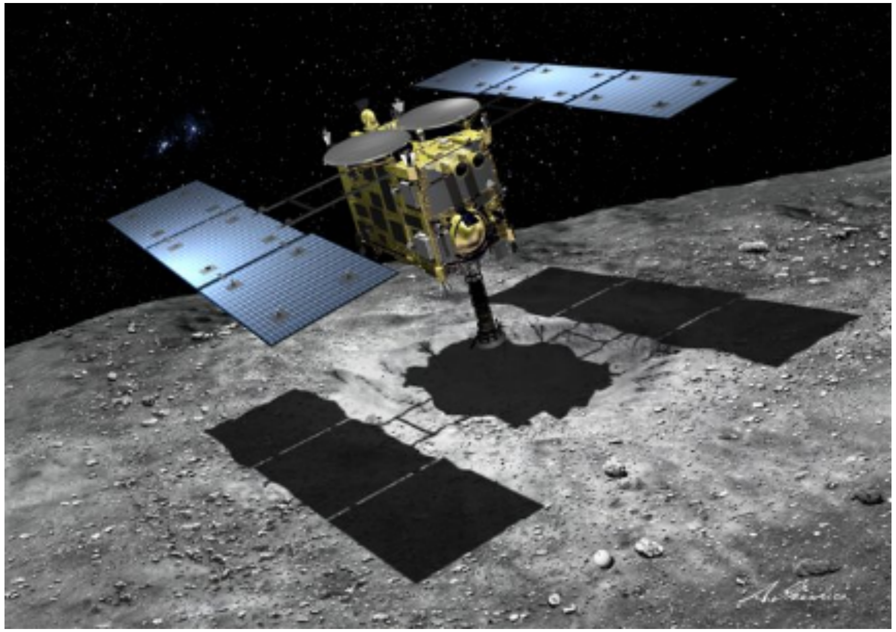
Overview of Hayabusa2

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

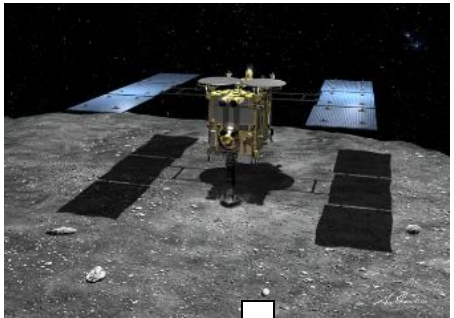
Primary instruments
Sampling mechanism, re-entry capsule, optical cameras, laser range-finder, scientific observation equipment (near-infrared, thermal infrared), impactor, miniature rovers.

Mission Flow

Launch
3 Dec 2014

Earth swing-by
3 Dec 2015

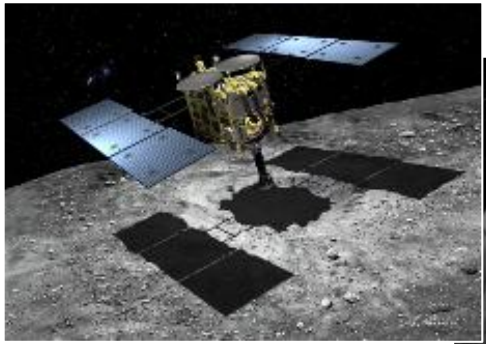
Arrival at asteroid
June 27, 2018



Examine the asteroid by remote sensing observations. Next, release a small lander and rover and also obtain samples from the surface.

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

Depart asteroid
Nov–Dec 2019



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

Earth return
late 2020

Sample analysis

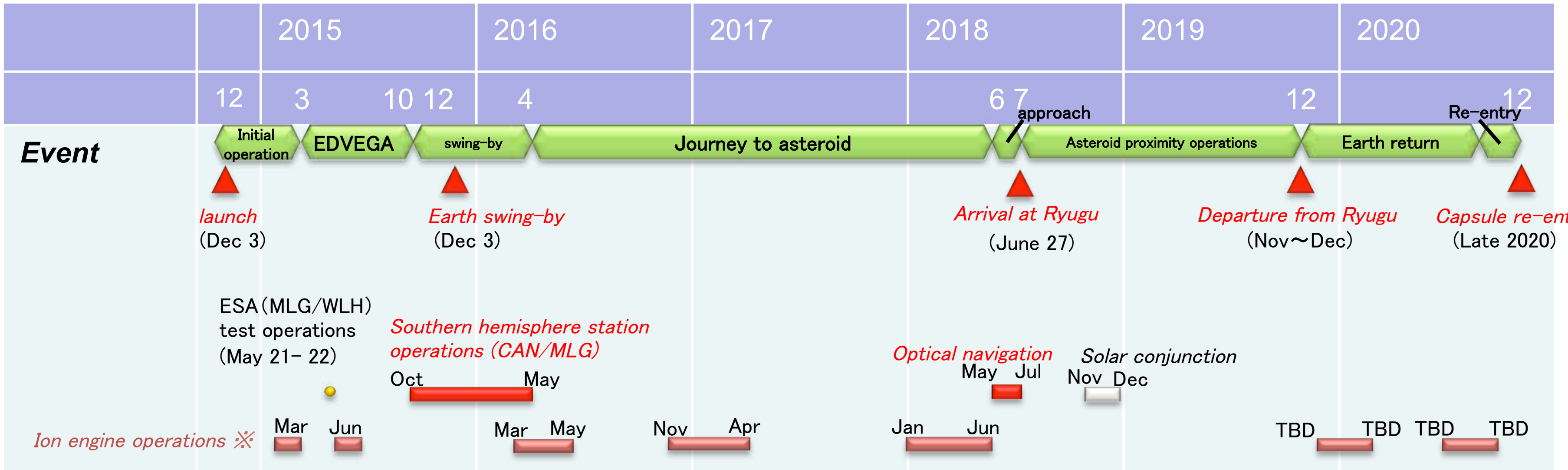
(Illustrations: Akihiro Ikeshita)

1. Current project status & schedule overview

Current status：

- MASCOT separation operation was performed between September 30 – October 4, with MASCOT successfully separating on October 3. MASCOT then proceeded to land on the surface of Ryugu and operated for about 17 hours.
- The next rehearsal for the first touchdown (TD1-R1-A) will be held from October 14 – 15.

Schedule overview:



2.MASCOT separation operation

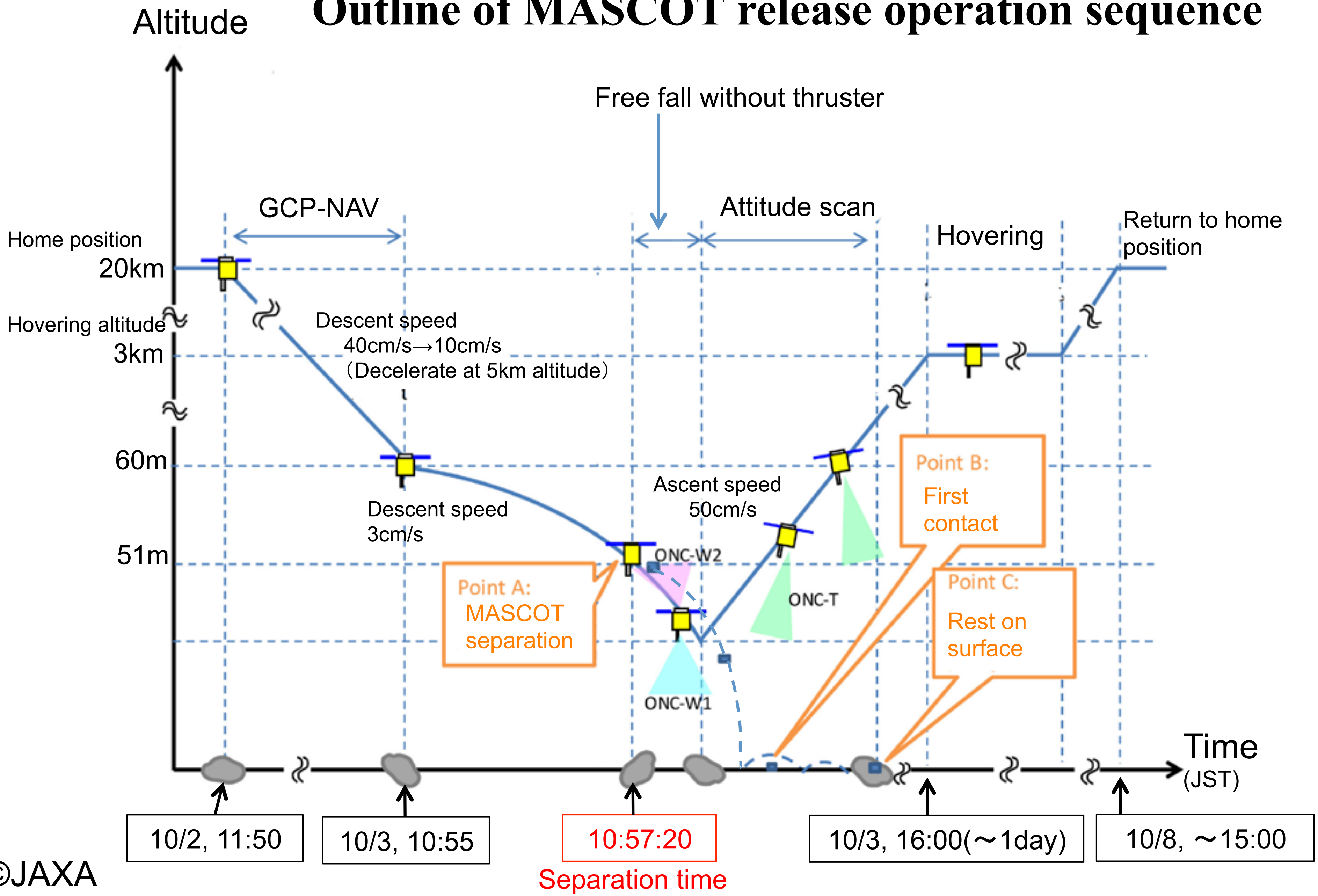
Operation outline:

- Sept. 28 : Agreement for separation received from MASCOT Project Manager, Dr Tra-Mi Ho.
- Oct 2, 11:50 (listed times are all JST): Begin descent
- Oct 3, 10:57:00: MASCOT separated at an altitude of 51m.
- October 4, 04:30: Declaration of mission completion received from Dr Tra-Mi Ho (MASCOT continued to operate for 17 hours after separation)
- We successfully communicated with MASCOT and confirmed that MASCOT landed on the surface of Ryugu. Data acquired from the observations conducted by MASCOT instruments were transmitted to the MASCOT team (Germany) .
- Confirmed that MASCOT moved via designed hop.
- The operation of MASCOT itself was conducted from the German side, with about 40 people in DLR Cologne. About 5 people in CNES Toulouse supported the operation.
- DSN (US Deep Space Network) level 2 support*
- The acquired data is also being used as reference information for touchdown operation.

*level 2 support:
= increased number of engineers
(We also requested double antennas)

2. MASCOT release operation

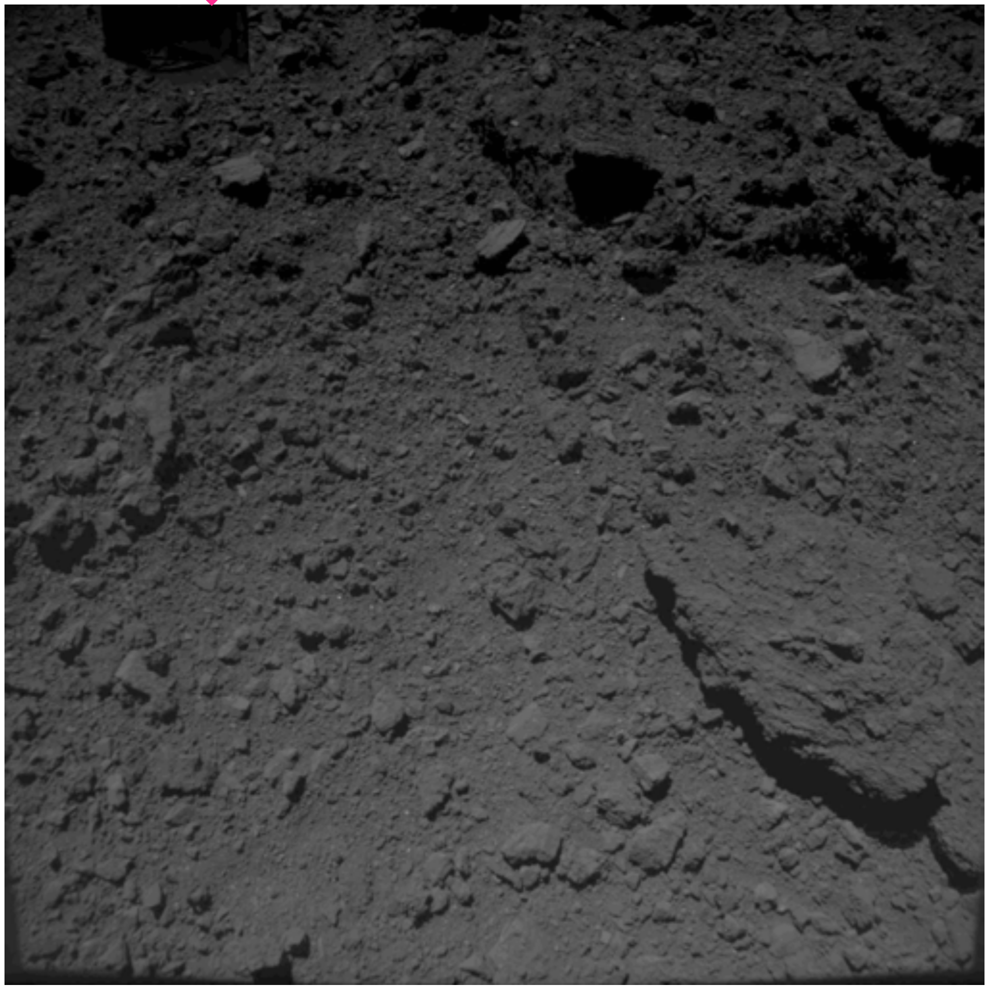
Outline of MASCOT release operation sequence



2. MASCOT separation operation

Watch here

MASCOT captured with the ONC-W2



Successful capture in 3 consecutive images by the Optical Navigation Camera – Wide angle (ONC-W2).

Image time：Oct. 3, 2018
1 shot 10:57:54
2 shot 10:58:04
3 shot 10:58:14

※Note: separation time 10:57:20

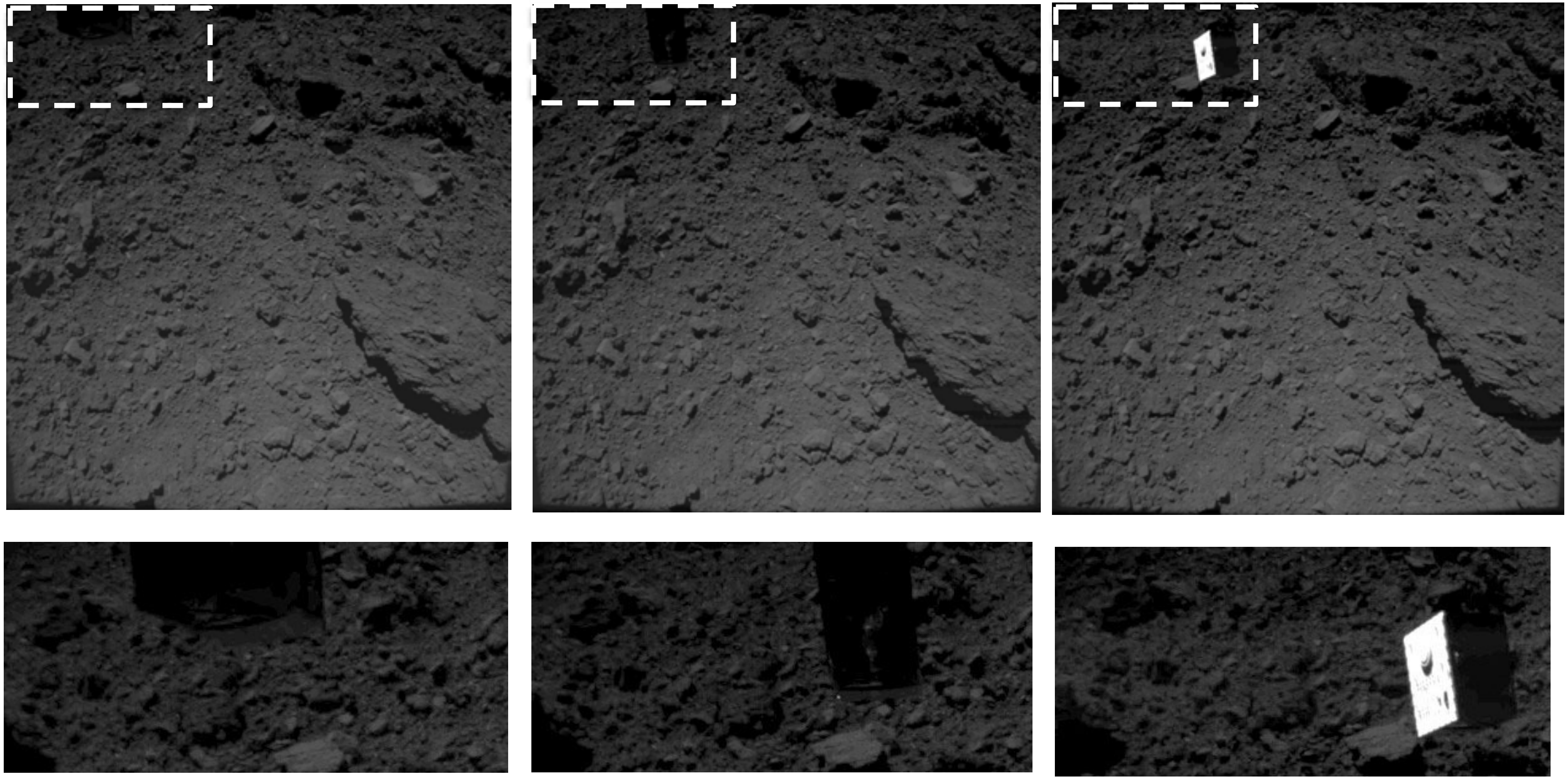
(Time : JST)

（3 image animation）

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

2. MASCOT separation operation

MASCOT captured with the ONC-W2

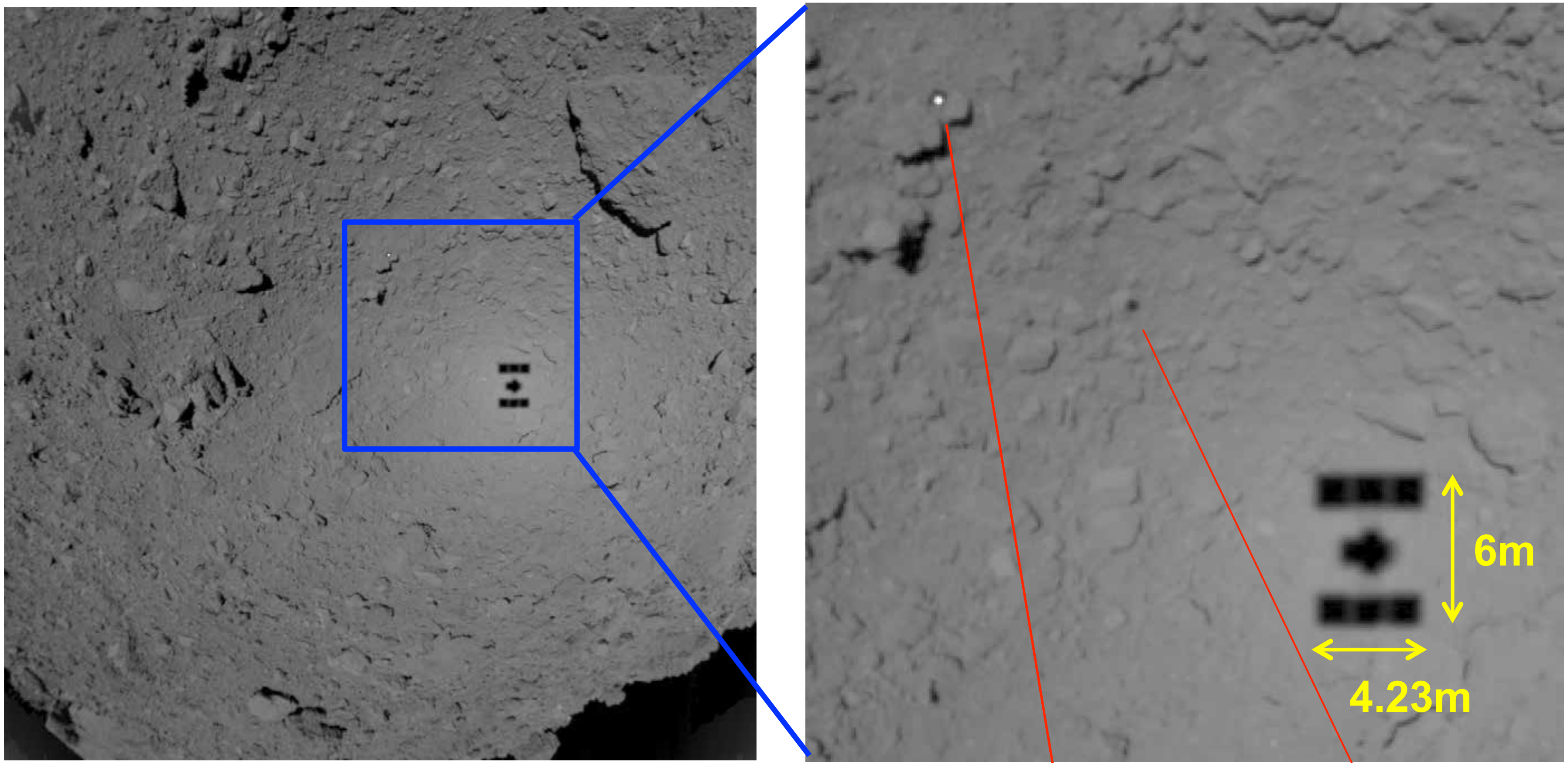


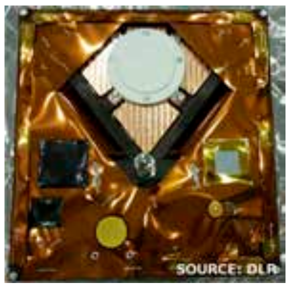
2018/10/3 10:57:54 2018/10/3 10:58:04 2018/10/3 10:58:14

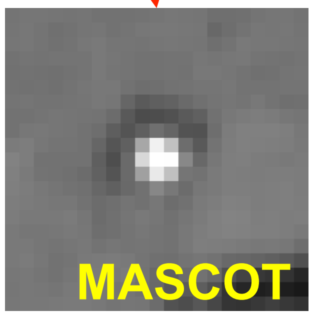
(Image credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, Aizu University, AIST.)

2. MASCOT separation operation

MASCOT captured with the ONC-W2







- Image capture time: Oct. 3, 2018 at 10:59:40（JST）
- MASCOT altitude：~35m

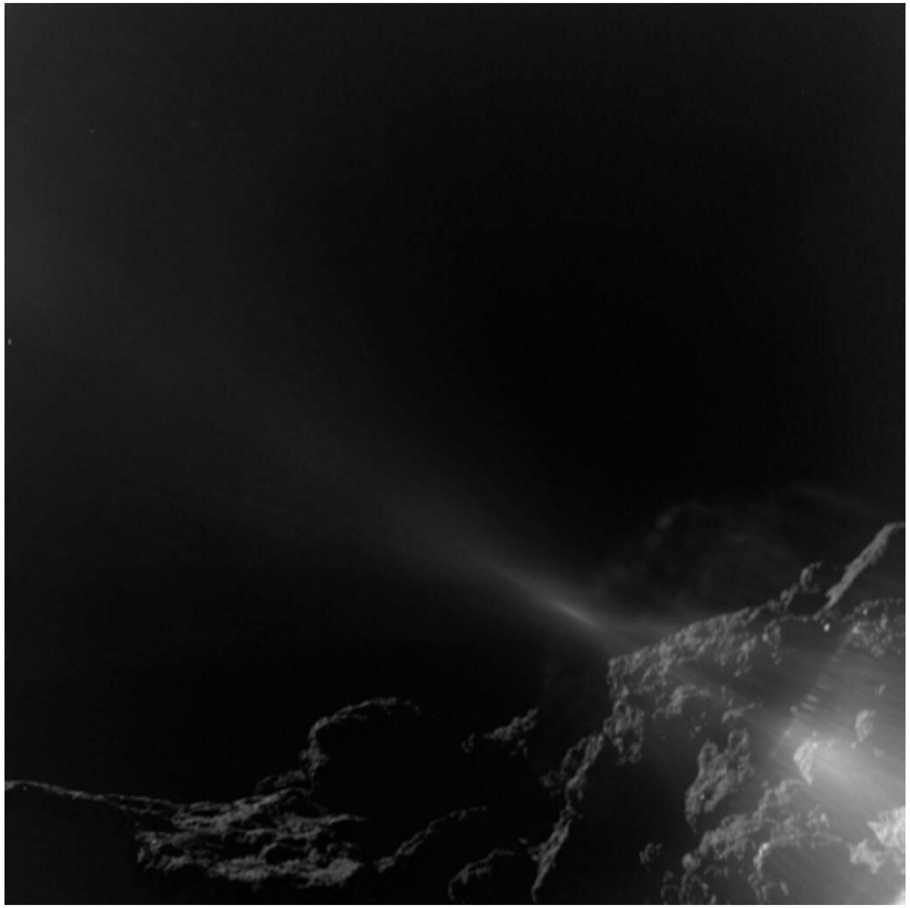
(Image credit: on previous page)

MASCOT underside (©DLR)

2. MASCOT separation operation

Images from the MASCOT camera (MASCAM)

Image from an altitude ~25m. The black dot in the upper right is the shadow of MASCOT.

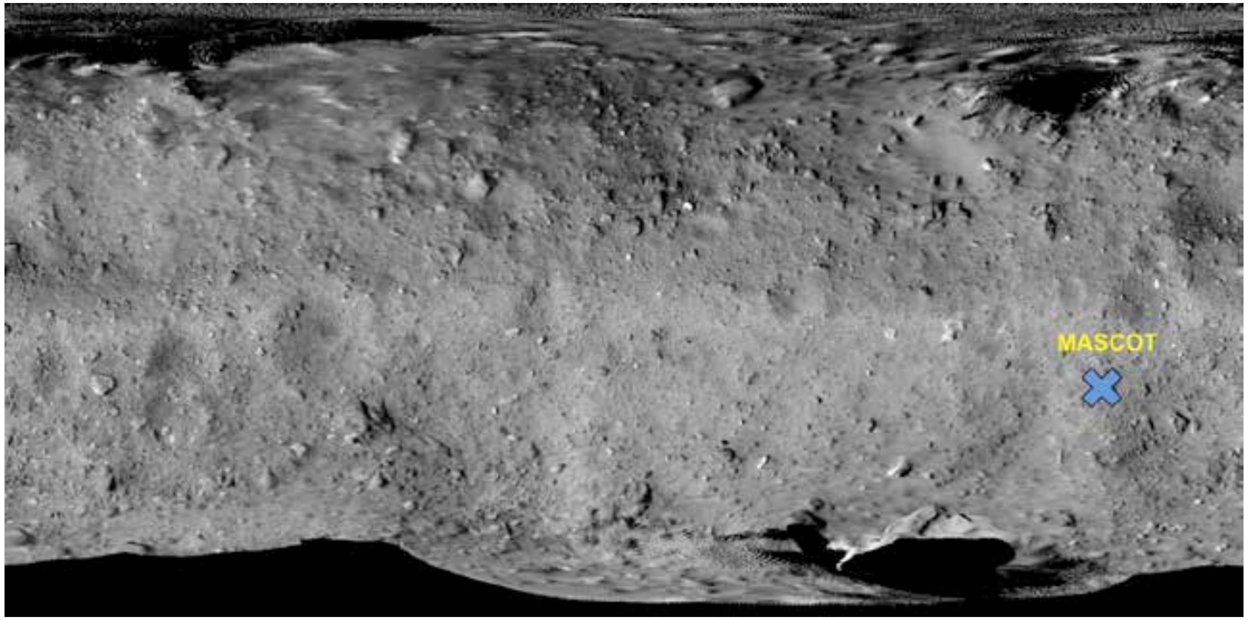


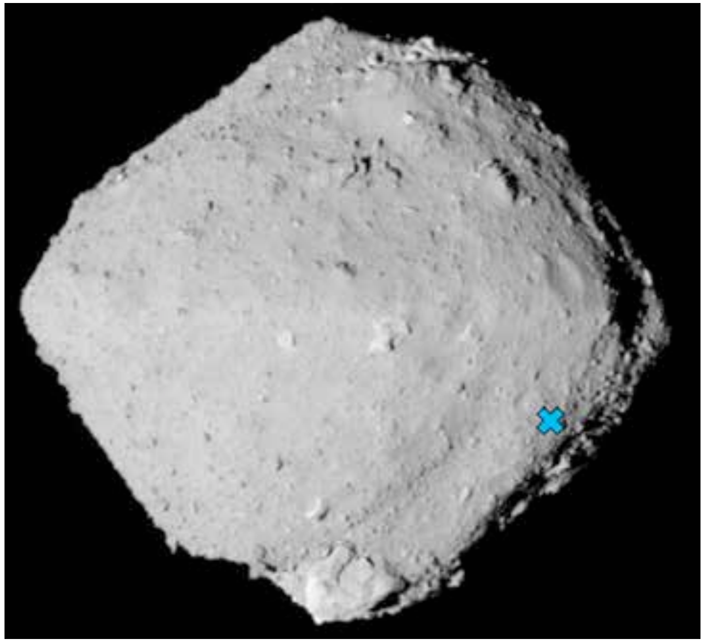
Images from the surface of Ryugu

（Image credit：MASCOT/DLR/JAXA）

2. MASCOT separation operation

MASCOT landing point



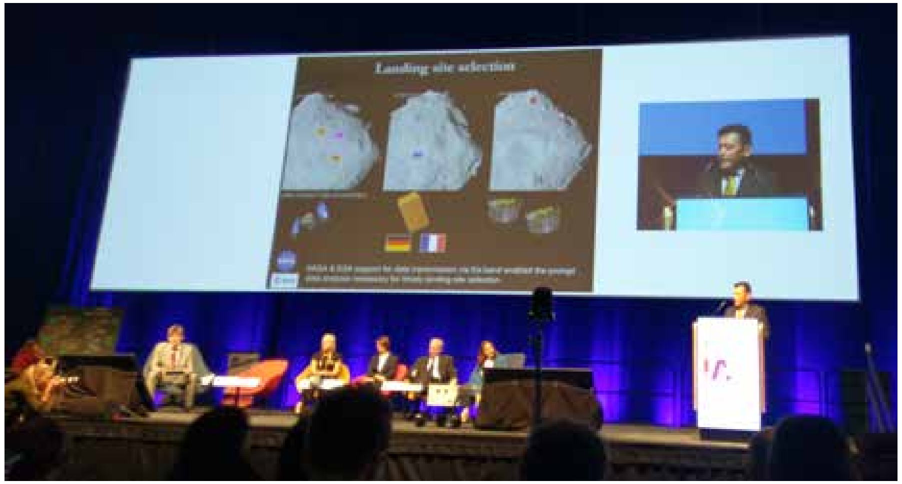


The blue ‘X’ shows the estimated landing site of MASCOT.

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

2. MASCOT separation operation

Reaction in Europe



Presentation of the newest information about Hayabusa2 including MASCOT at IAC (International Astronautical Congress) in Bremen, Germany on October 5, 2018.
Photo by Dr. Hikaru Yabuta

<u>MASCOT press conference</u>

MASCOT's Path on the Asteroid Ryugu
Friday, October 12, 2018, 10:30am
DLR Capital Office Berlin

Dear MASCOT-team

2 days after the landing of MASCOT on Ryugu, and analyzing the first data and images, it is time for me to thank all of your for an outstanding job.

When we started the MASCOT-project 7 years ago, it was clear that it will become hard work to build, to integrate, and to test a small lander equipped with 4 instruments in only 2 1/2 years time. I know that all of you had been engaged very much over a long time before launch and later during cruise phase for landing preparation. I like to thank all of you, and in particular our colleagues and partners in JAXA and CNES, for this work which made a small spacecraft landing a great event in space. To my knowledge of today, all systems worked nicely and made it possible to record as scheduled which demonstrated a careful and high quality work of all contributors as well as a great team spirit.

I am sure that the data recorded during the 17 hours operation on Ryugu's surface will become the basis of important scientific results.

Thank you again!

With regards
Hansjoerg Dittus

Message from Hansjörg Dittus, DLR Executive Board Member for Space Research and Technology

3. Touchdown rehearsal and plan

■Re-examination of future operations

- So far, 6 descent operations have been performed. Based on the performance of the navigation guidance and the surface of Ryugu, the revised schedule is as follows:

（Note）Descent operations: BOX-C operation, medium altitude operation, gravity measurement operation, TD1-R1 (first touchdown (TD) rehearsal), MINERVA-II operation, MASCOT operation.

■New Schedule

- Oct. 14- 15 : TD1-R1-A（equivalent to the second TD rehearsal)
- Oct. 24 - 25 : TD1-R3（equivalent to the third TD rehearsal)
- Late Nov - Dec : Conjunction operation
- After Jan 2019 : First touchdown

(Note）There is no TD-R2

※The operation schedule after January 2019 will be determined based on the results up to TD1-R3.

3. Touchdown rehearsal and plan

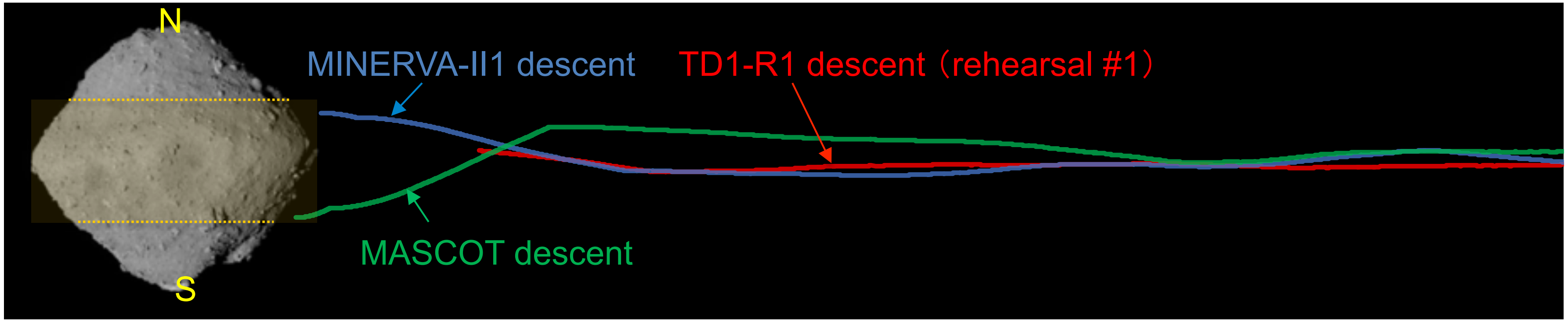
Basic policy for touchdown：
Proceed by confirmed each step one-by-one

Story so far:

- Jul. 17〜25 : BOX-C operation → hovering at approximately 6km altitude
- Jul. 31〜 Aug. 2 : Medium altitude operation → down to approximately 5km altitude using GCP-NAV
- Aug. 5 〜 10 : Gravity measurement operation → descent to 851m altitude
- Aug 17 : LSS based on current observation data (LSS: Landing site Selection)
- Sep. 10 〜12 : TD1-R1 → descent stopped at 600m altitude
  - ・Error in LIDAR（laser altimeter）measurement
  - ・LRF（Laser Range Finder） could not be confirmed
- Sept. 19〜21 : MINRVA-Ⅱ1 separation operation → descent to 55m altitude
  - ・LIDAR measurement confirmed to have no problem
  - ・High resolution observation data of TD candidate area obtained from navigation guidance data.
- Sept. 30 〜Oct. 4 : MASCOT separation operation → descent to 51m altitude.
  - ・ High resolution observation data of TD candidate area obtained from navigation guidance data.

3. Touchdown rehearsal and plan

Current results and information (1)
＜Navigation guidance accuracy＞



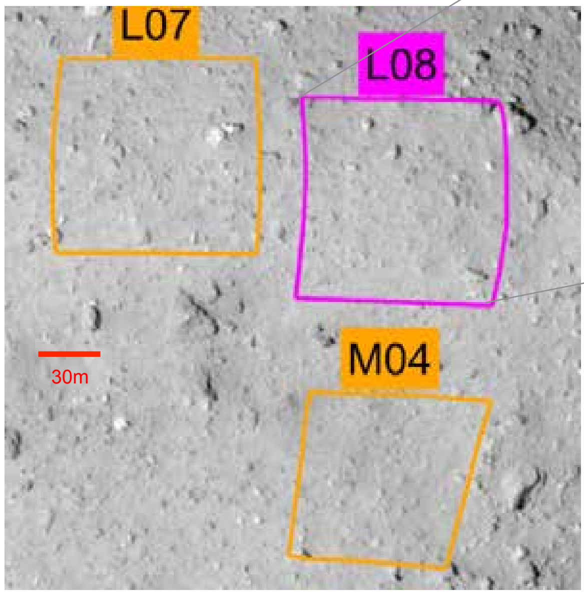
Trajectory of low altitude descents so far（©JAXA）

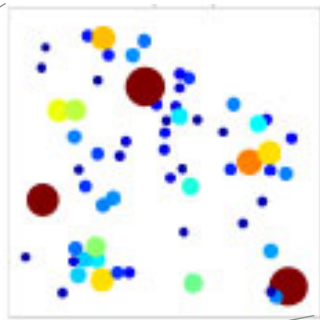
- TD1-R1 descended to the equator, MINERVA-II1 operation was in the northern hemisphere and the MASCOT operation was in the southern hemisphere.
- Hayabusa2’s guidance was confirmed to have an accuracy of about 10m down to an altitude of about 50 over the entire latitude ±30°.

3. Touchdown rehearsal and plan

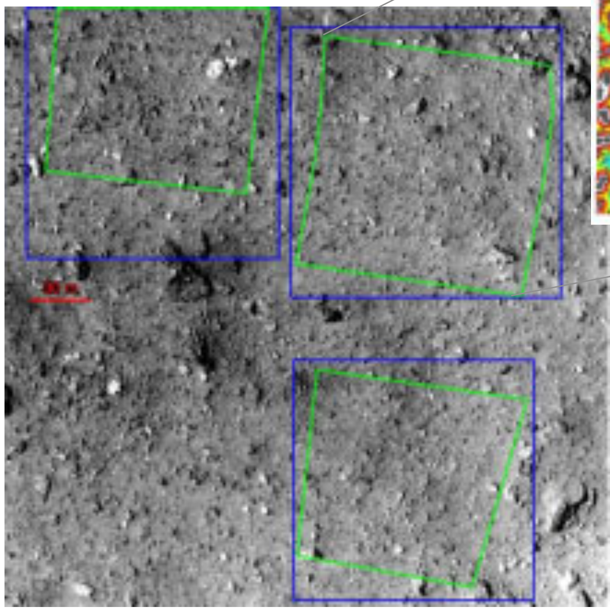
Current results and information (2)
＜Ryugu topology＞

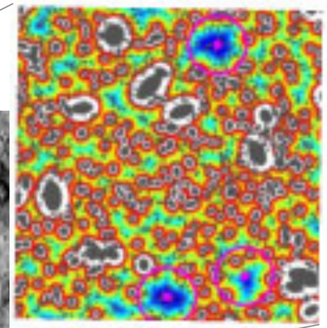
◆Data as of August





◆Current data



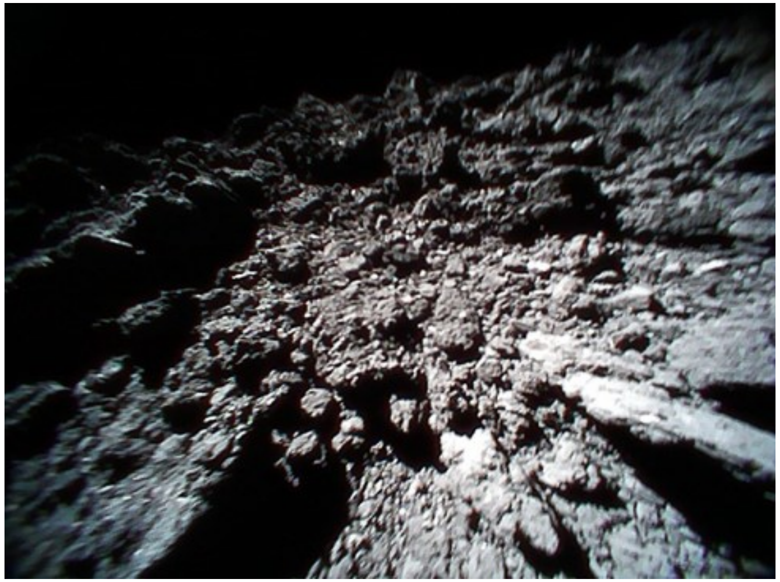


- From observations so far, the distribution of boulders about 50cm or larger has been determined for the TD candidate sites（L08，L07，M04）.
- There are many boulders in the class larger than 50cm that hinder landing safely in the landing candidate area. Flat areas most suitable for landing are extremely limited.

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

3. Touchdown rehearsal and plan

Current results and information (3)
＜Surface observations by rover and lander＞



©JAXA

©MASCOT/DLR/JAXA

- Detailed analysis of surface conditions from images taken by MINERVA-II1 and MASCOT.
- The images do not show a landscape of "sand interspersed with boulders" but rather "the ground itself consists of large and small rocks".

3. Touchdown rehearsal and plan

Checklist before touchdown:
＜Overcoming severely rugged topology, confirmation of the spacecraft at ultralow altitude＞

- Navigation guidance accuracy down to an altitude lower than 50m ← check during TD1-R1-A
- Operation characteristics of LRF ← check during TD1-R1-A
- Target marker (TM) tracking characteristics ← confirm during TD1-R3 if possible

※Previous plans did not plan to check the TM tracking characteristics, but this independent advance check was introduced in the new plan.

After confirming these points, introducing pinpoint touchdown technology will also be considered. (see reference page)

Note : Target marker tracking (TMT)
Target markers are recognized in images obtained by the optical navigation camera. The spacecraft understands the locations of the target markers and navigates itself for touchdown.

3. Touchdown rehearsal and plan

■ Plan during TD1-R1-A

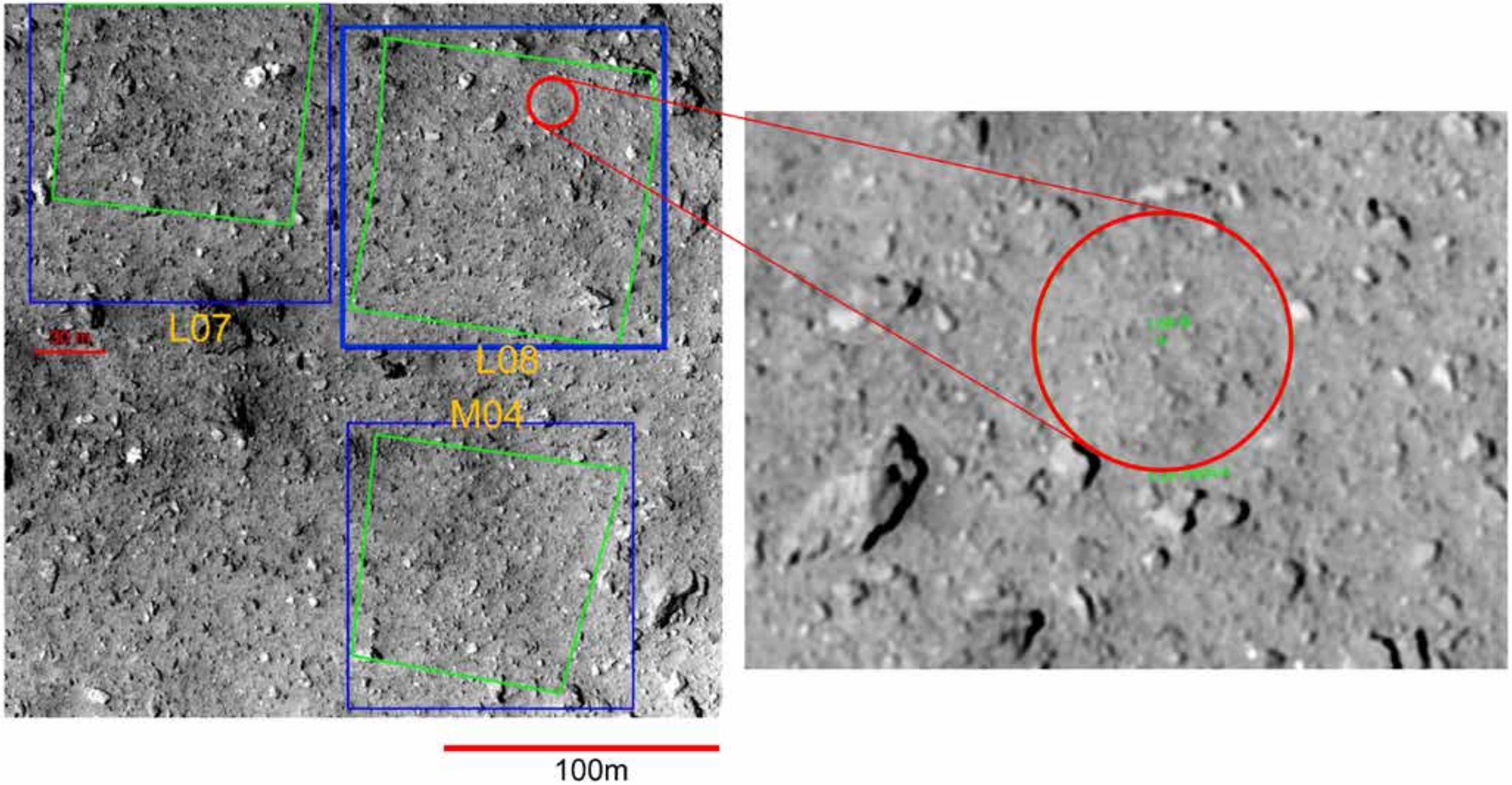
- Confirmation of navigation accuracy.
- Understand characteristics of LRF.
- LRF only performs a measurement and is not used here for spacecraft control.

■ Plan during TD1-R3

- Confirmation of navigation accuracy.
- LRF measurement data used for spacecraft control.
- Potentially separate target markers (TM).

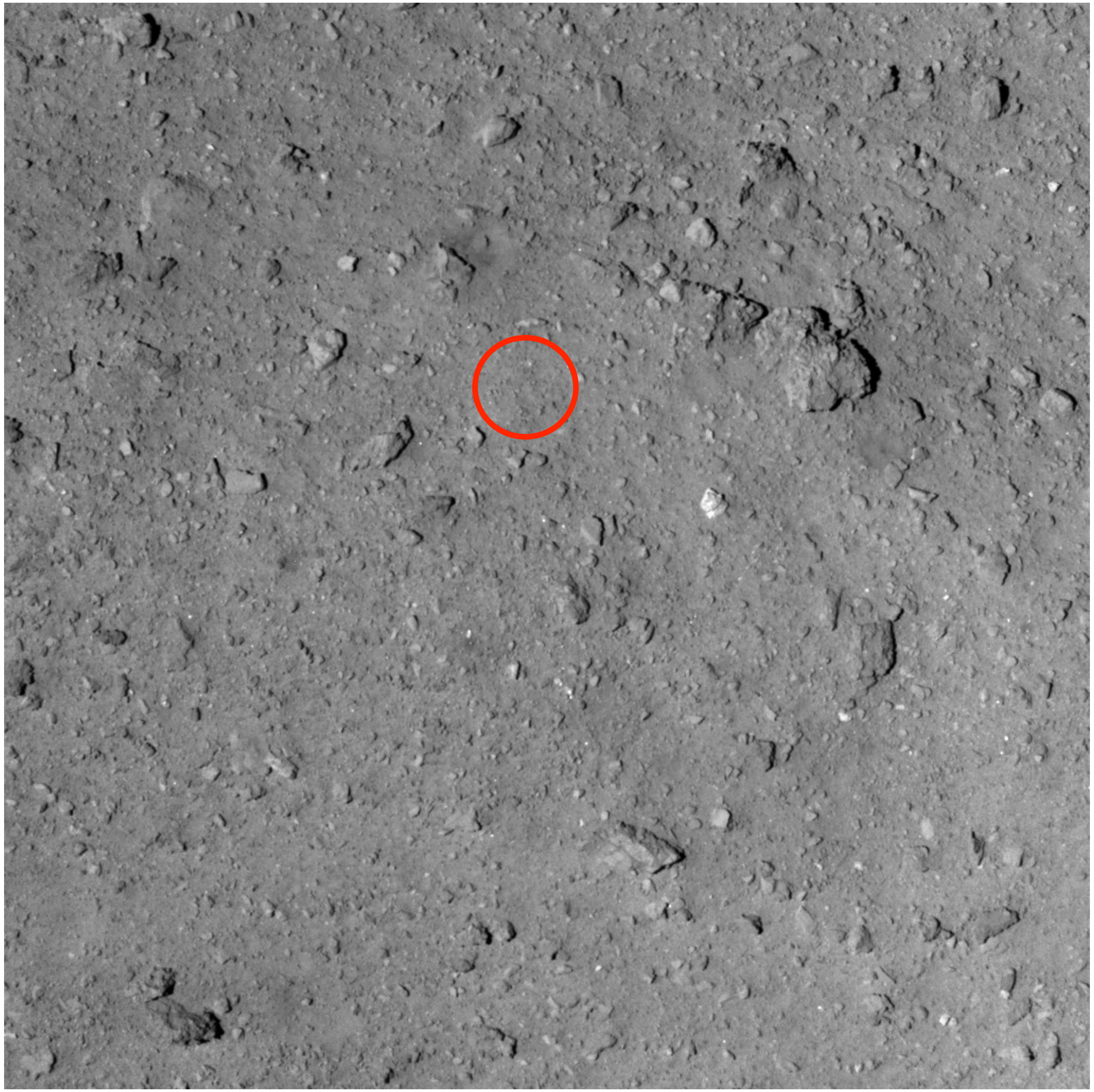
3. Touchdown rehearsal and plan

Touchdown candidate side：L08-B



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

3. Touchdown rehearsal and plan



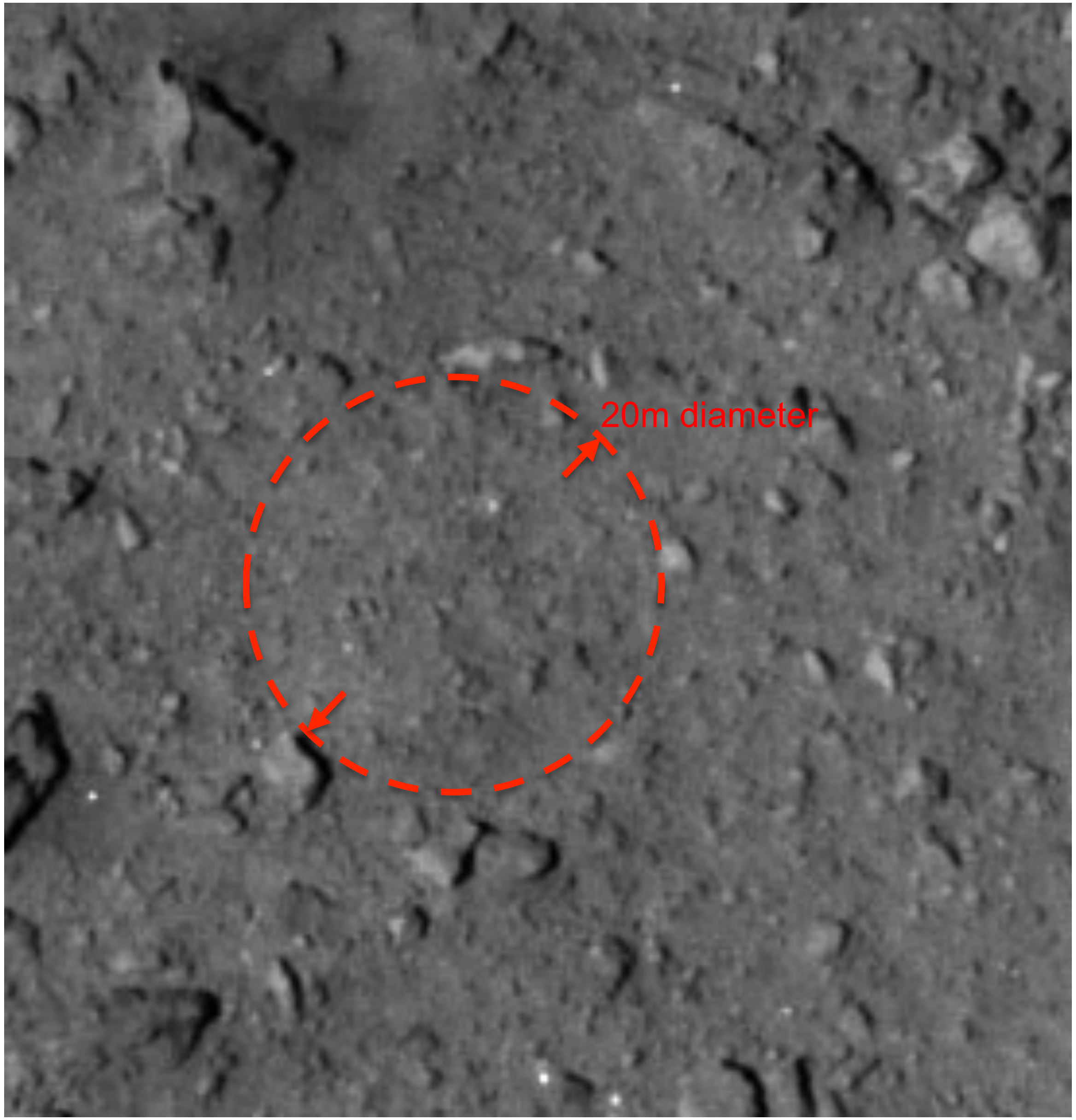
L08-B

L08-B images by the ONC-T during the MASCOT separation operation.

Image data：Oct. 3, 2018, 05:41 JST.
Image altitude: ~1.9km
Resolution　：20cm/pixel

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

3. Touchdown rehearsal and plan



L08-B

Close-up of previous page image

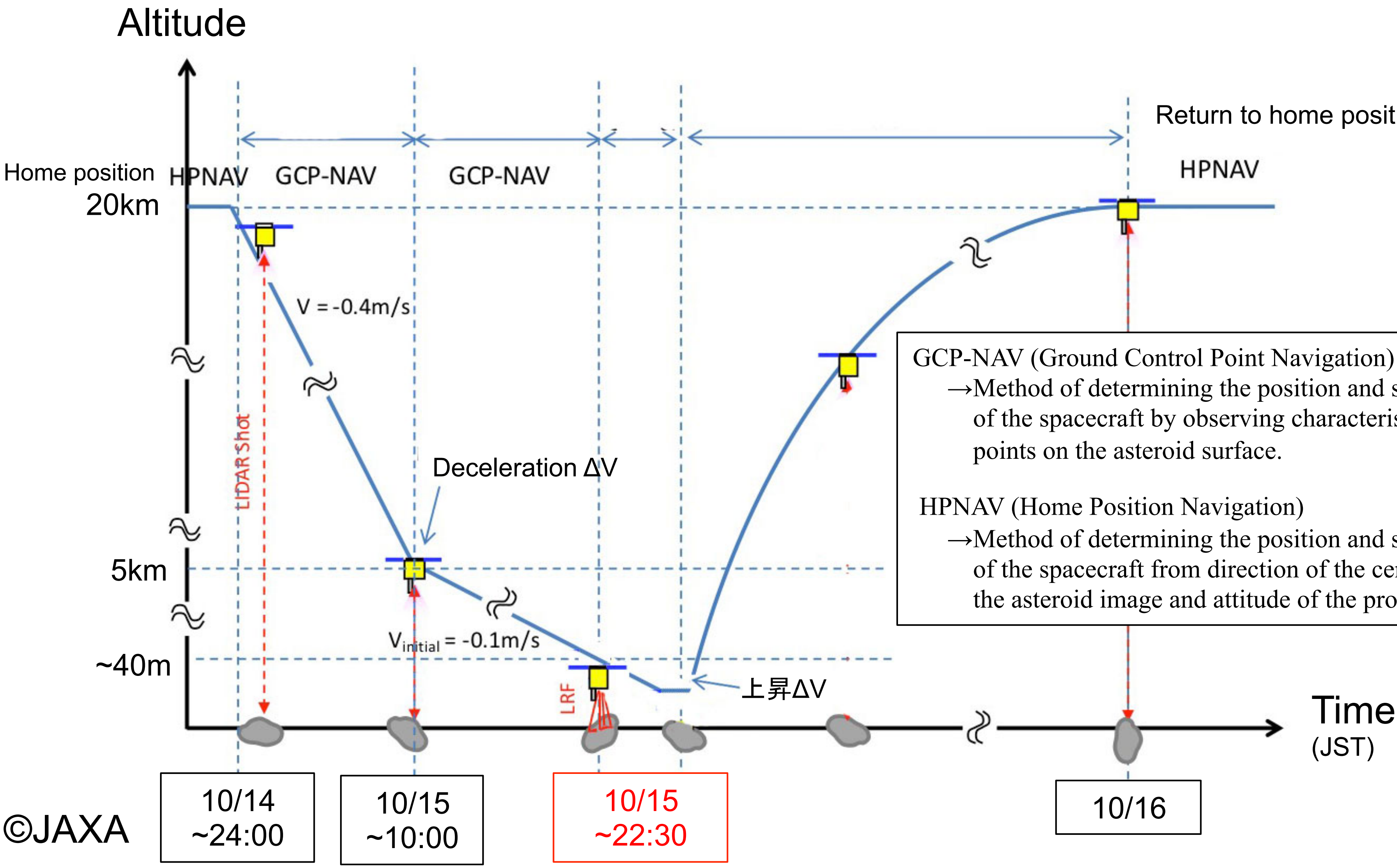
L08-B images by the ONC-T during the MASCOT separation operation.

Image data：Oct. 3, 2018, 05;41 JST.
Image altitude: ~1.9km
Resolution ：20cm/pixel

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

3. Touchdown rehearsal and plan

TD1-R1-A schedule



GCP-NAV (Ground Control Point Navigation)
→Method of determining the position and speed of the spacecraft by observing characteristic points on the asteroid surface.

HPNAV (Home Position Navigation)
→Method of determining the position and speed of the spacecraft from direction of the center of the asteroid image and attitude of the probe.

4. Future plans

■Operation schedule

- Oct. 14 – 15 : TD1-R1-A（2nd touchdown rehearsal）
- Oct 24 - 25 : TD1-R3（3rd touchdown rehearsal）

■Media briefings

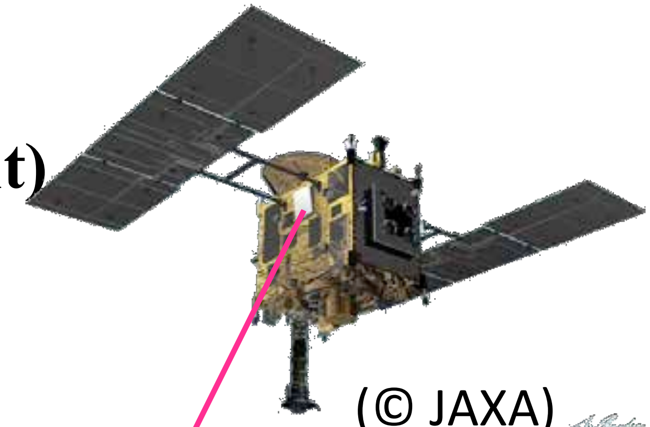
- Oct 23 (Tue) 16:00 JST～　Reporter's presentation @ Ochianomizu
- Nov 8 (Thur) 11:00 JST11～　Press briefing @ Ochianomizu

Reference

3. MASCOT release operation

MASCOT System Overview

MASCOT (Mobile Asteroid Surface Scout)


(© JAXA)

- Developed by DLR (German Aerospace Center) in close cooperation with CNES (French Space Agency)
- Agile, lightweight & compact landing platform for in-situ asteroid research
- Lander Module mass: ~9.8 kg
- Lander Module size: 0.275 x 0.290 x 0.195 m
- Carries Four Scientific Payloads: MASCAM, MicrOmega, MARA, and MASMAG

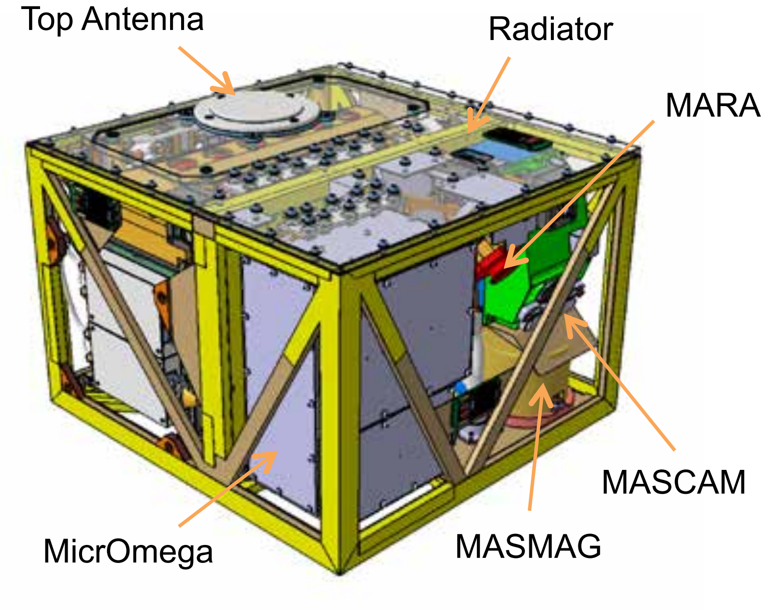

Flight Model (© DLR)

3. MASCOT release operation

MASCOT System Overview

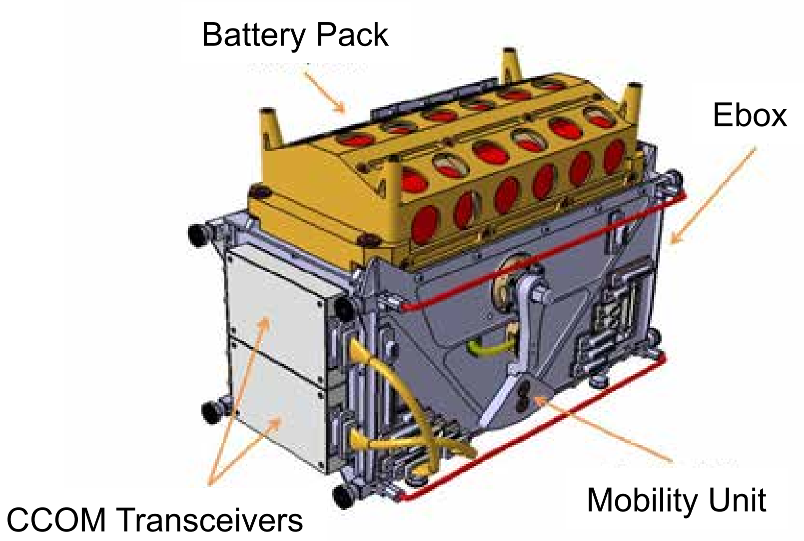
Scientific instruments aboard MASCOT

Device	Function
Wide-angle camera (MASCAM)	Imaging at multiple wavelengths
Spectroscopic microscope (MicrOmega)	Investigation of mineral composition and characteristics
Thermal radiometer (MARA)	Surface temperature measurements
Magnetrometer (MASMAG)	Magnetic field measurement



MASCOT Bus System

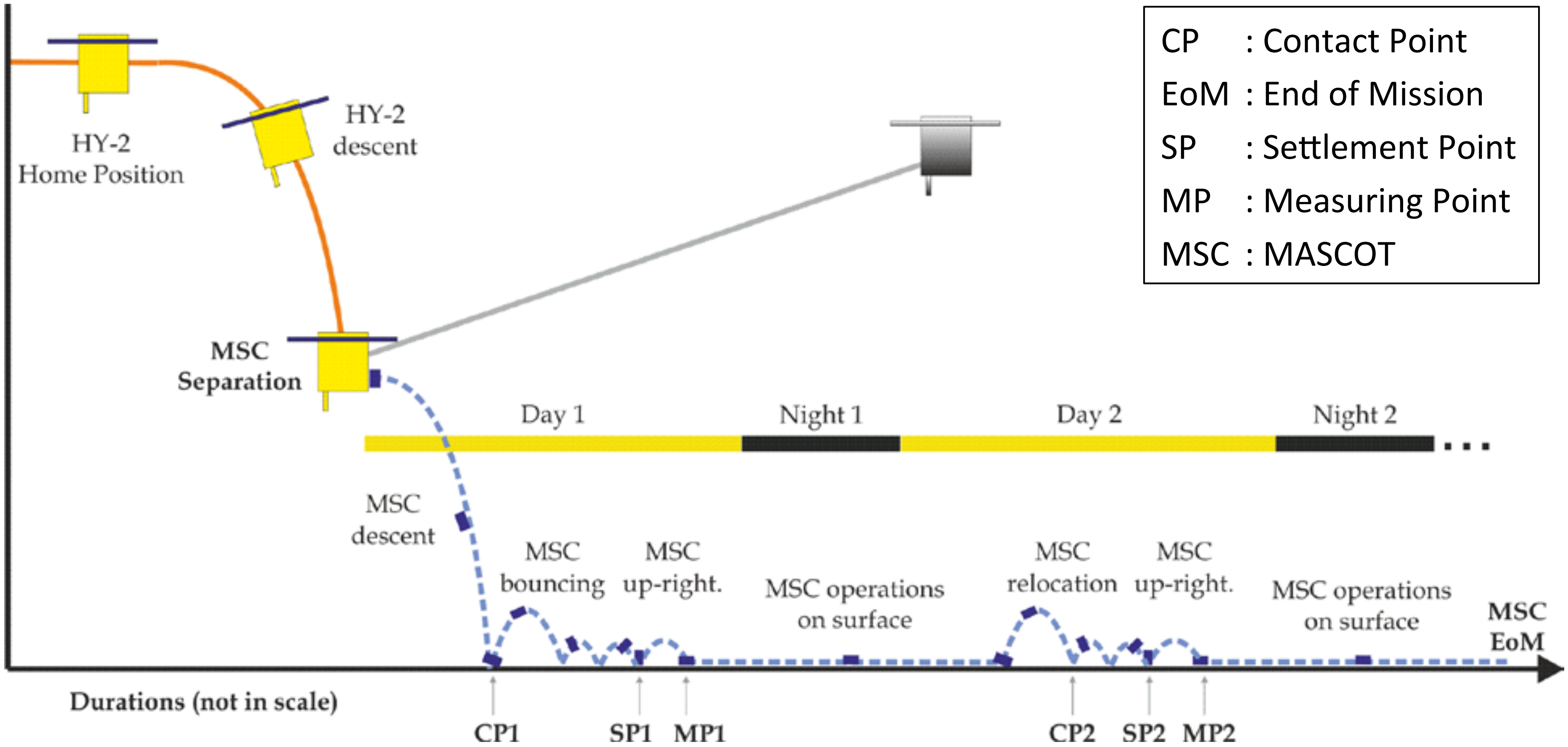
- Power: Primary lithium battery
- Communication: Communication system using transceivers same as Minerva-II rovers
- Mobility: Up-righting and hopping mechanism using motor and excenter mass
- GNC: MASCOT attitude determination using proximity sensors



3. MASCOT release operation

MASCOT On-Asteroid Operation

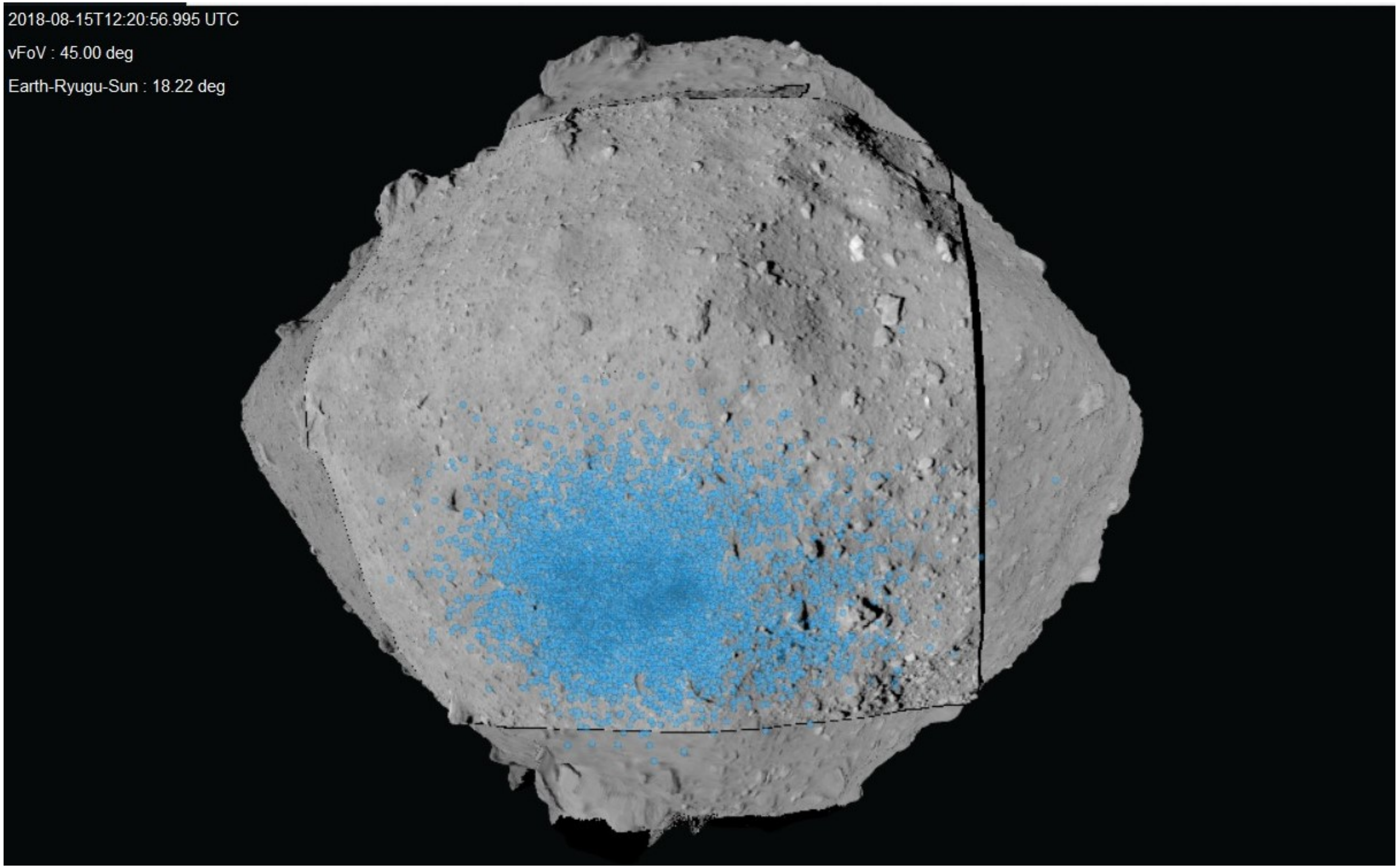
Baseline MASCOT Activities after the Separation



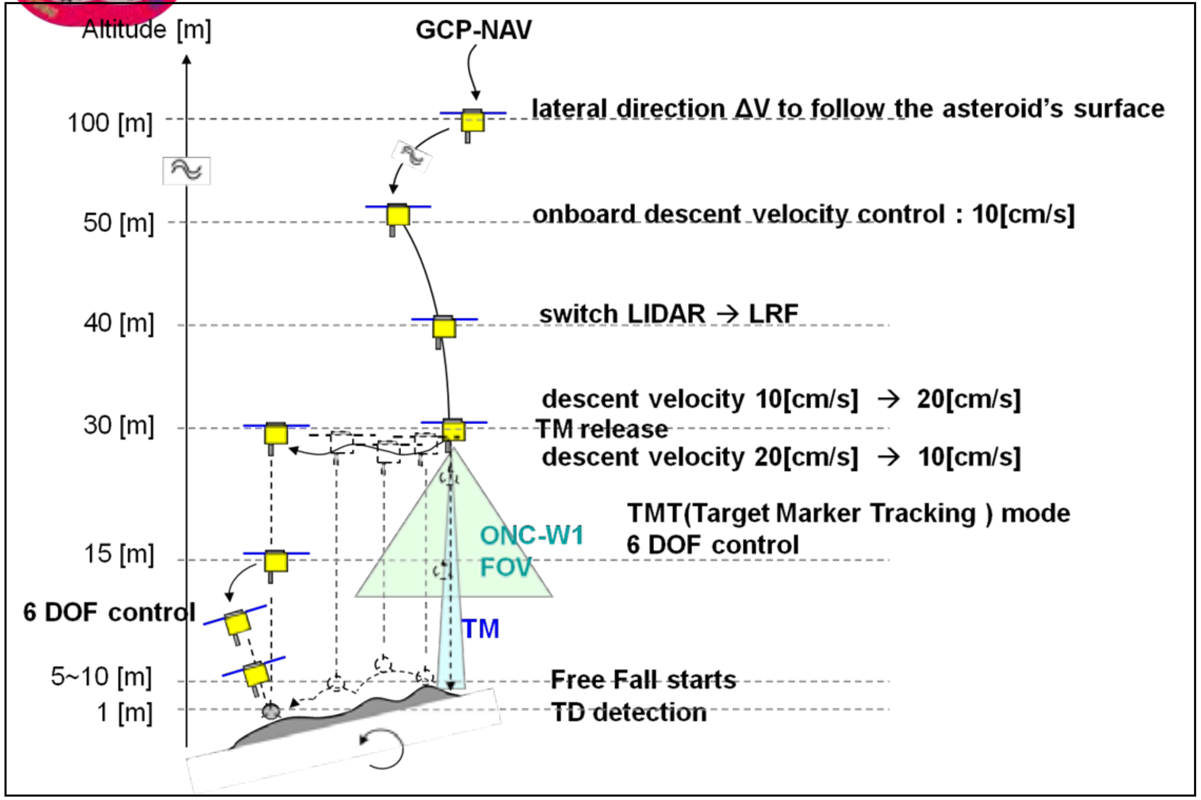
CP	: Contact Point
EoM	: End of Mission
SP	: Settlement Point
MP	: Measuring Point
MSC	: MASCOT

3. MASCOT release operation

MASCOT landing site



Pinpoint touchdown



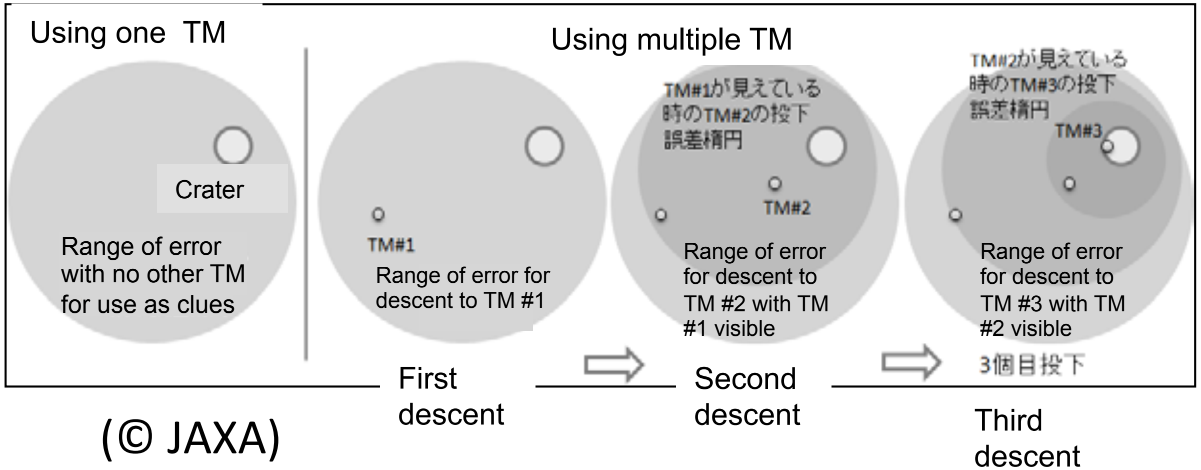
- Target Markers (TM)

✓ TM separate at an altitude of several tens of meters, and flash lamps intermittently illuminate TM while cameras image them.

✓ By comparing differences in images when flash lamps are lit and when they are not, we can accurately extract TM without effects from surface patterns or sunlight.

✓ Facing toward identified TM, descend to the asteroid while using laser altimeter information to determine attitude and distance to the surface.

✓ 6-degree-of-freedom (position + attitude) gas jet injection control with high target tracking while minimizing fuel consumption is also a key technology.



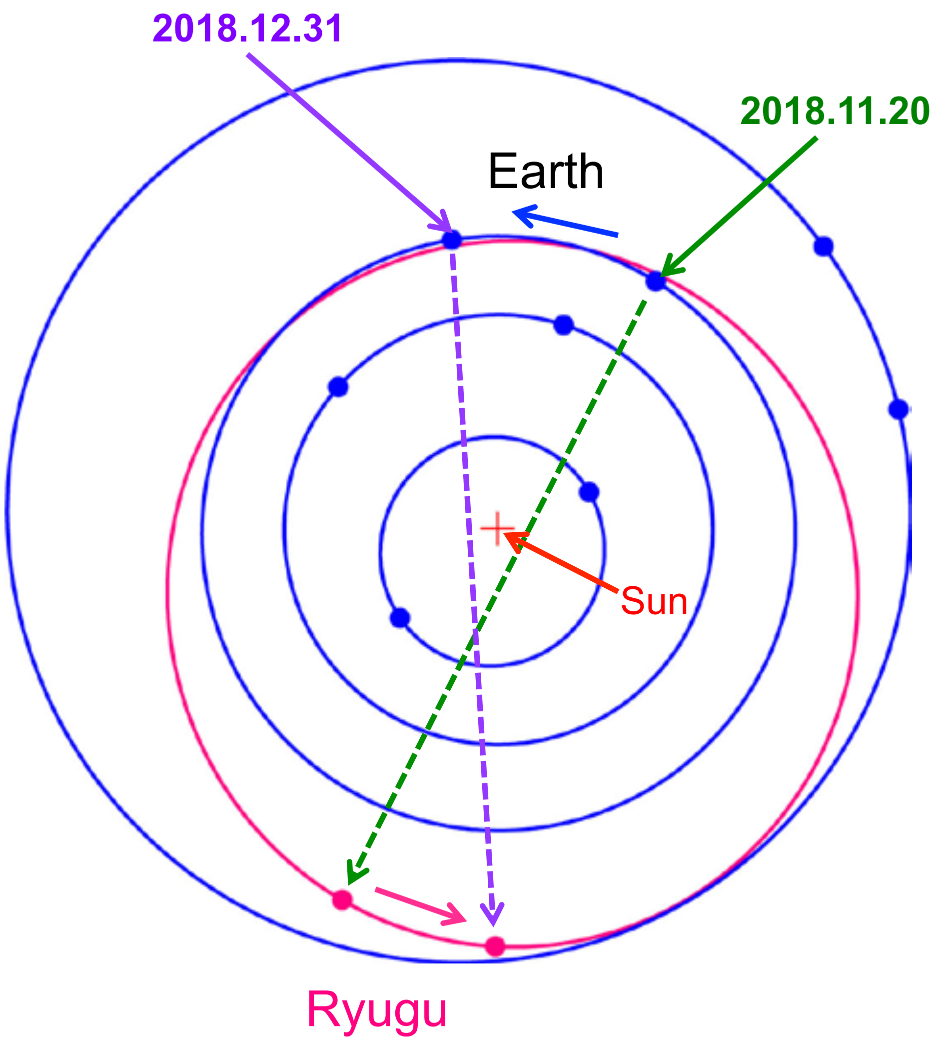
- Use of multiple TM

✓ We will touch down near the artificial crater, and attempt to retrieve samples from exposed areas.

✓ We expect the artificial crater to have a diameter of around several meters. By approaching the destination point based on clues from multiple sequential TM, we can perform the touchdown with higher precision (a pinpoint touchdown).

Conjunction operation

- "Conjunction" for spacecraft operation refers to the case where the spacecraft is in the direction that almost directly overlaps with the Sun when viewed from Earth.
- The alignment means that communication with the spacecraft is not secure due to radiowaves radiated by the Sun.
- In this period, critical operation is not carried out.
- For Hayabusa2, the duration of this period is from late November 2018 – end of December.



Positions of Ryugu and the Earth