Asteroid explorer, Hayabusa2, reporter briefing

July 25, 2017

JAXA Hayabusa2 Project

Topics

Regarding Hayabusa2,

- Results from the 2nd touchdown operation

Contents

Overview of Hayabusa2

<u>Objective</u>

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.

<u>Expected results and effects</u>

・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.

<u>Features:</u>

・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.

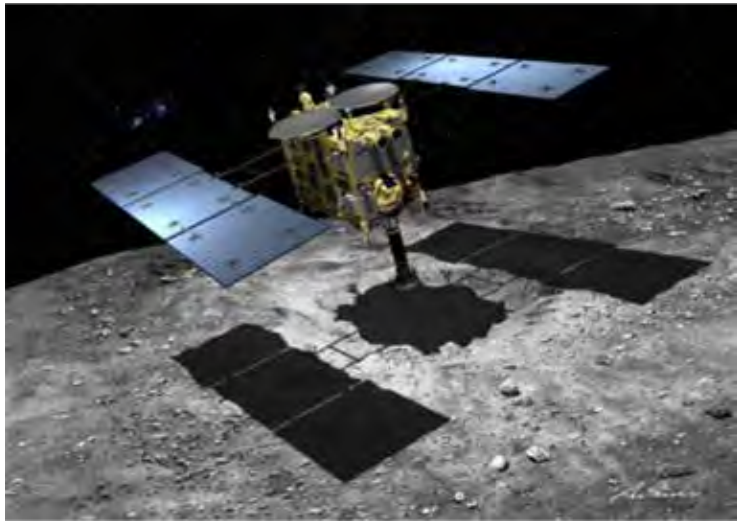
・Comparison with results from Hayabusa will allow deeper understanding of the distribution, origins, and evolution of materials in the solar system.

<u>International positioning:</u>

・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)

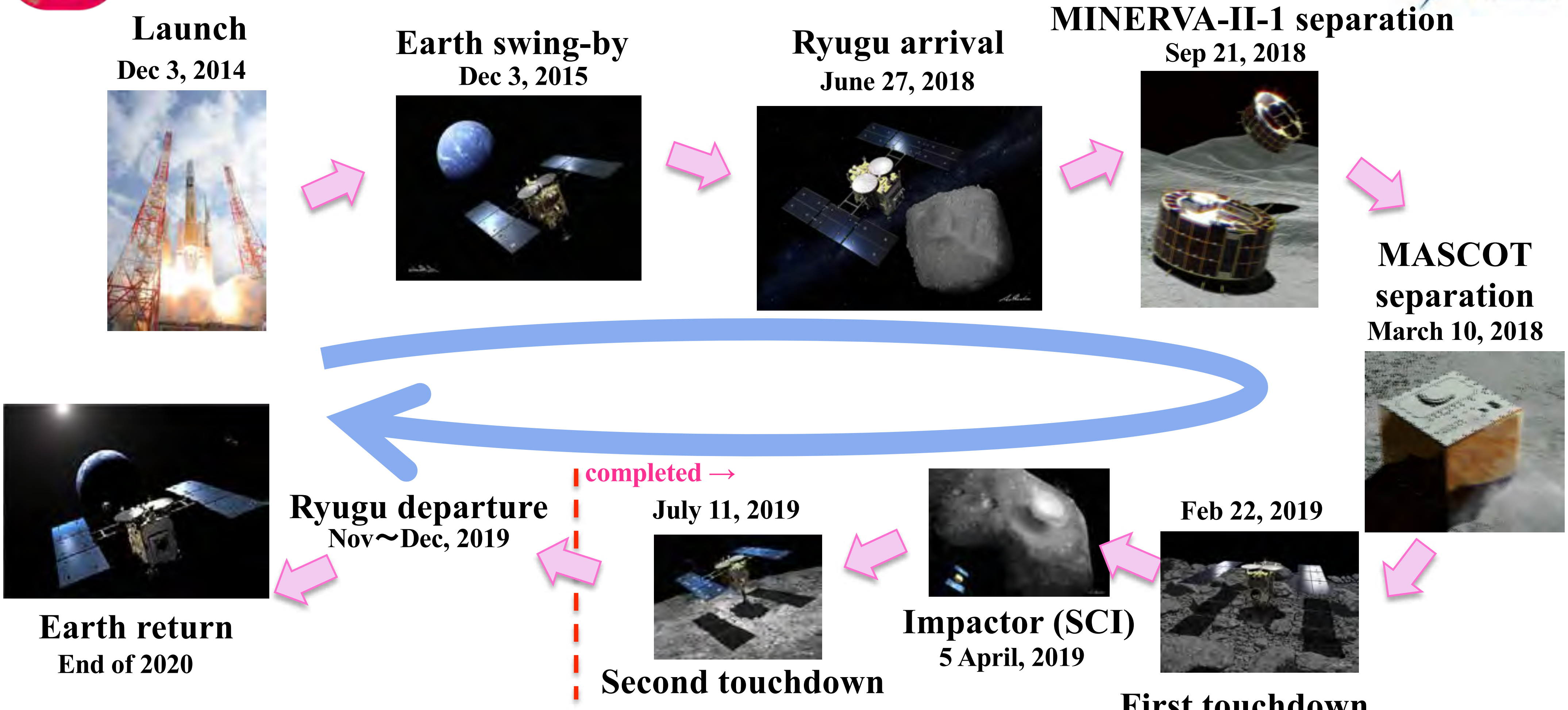
<u>Hayabusa 2 primary specifications</u>

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

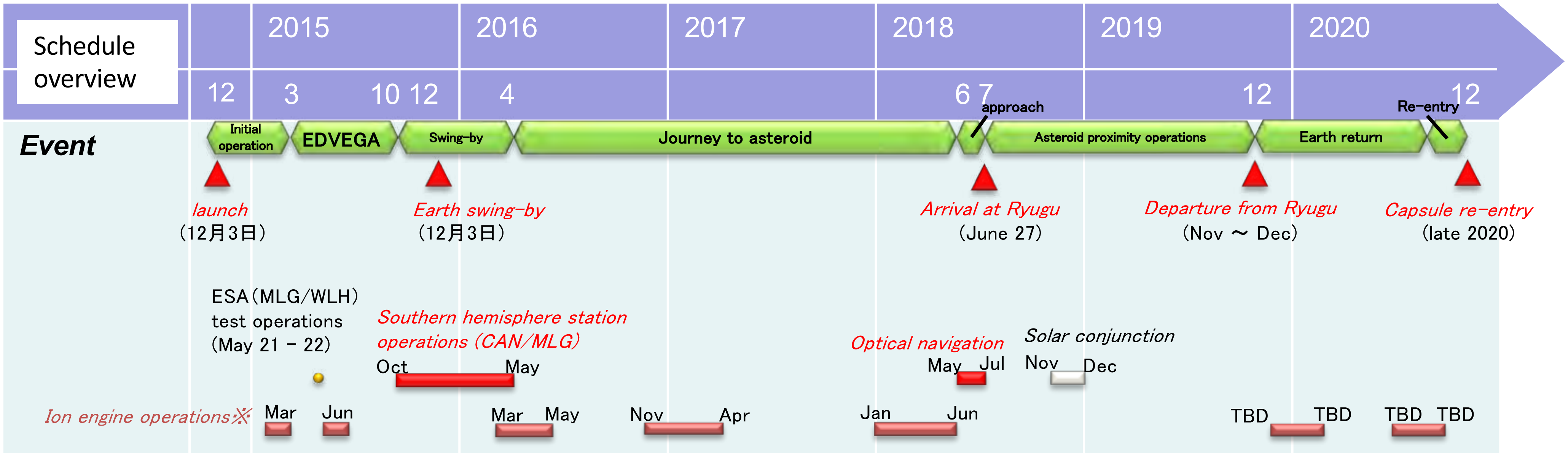


(image credit: illustrations including spacecraft by Akihiro Ikeshita, others by JAXA)

1. Current project status & schedule overview

Current status :

- Implemented the second touchdown from July 9 – 11.
- Touchdown was carried out safely and Hayabusa2 returned to the home position at about 20 km from the center of Ryugu on July 12.
- BOX-C operation is currently underway (7/20 ~ 31). The lowest altitude will be about 5km during 7 / 25~27.



2. The 2nd touchdown operation

- 2nd touchdown operation：2019/7/9～11
- Touchdown date & time： 2019/7/11、10:06:18 JST（on-board time）
- Touchdown location：C01-Cb（Target marker drop area）
- Implemented pinpoint touchdown targeting TM-A dropped during PPTD-TM1A.
- Touchdown was detected through fluctuations in the LRF-S2 ranging value due to deformation of the sampler horn upon touchdown.
- Touchdown position accuracy is 60 cm.

2. The 2nd touchdown operation

First release

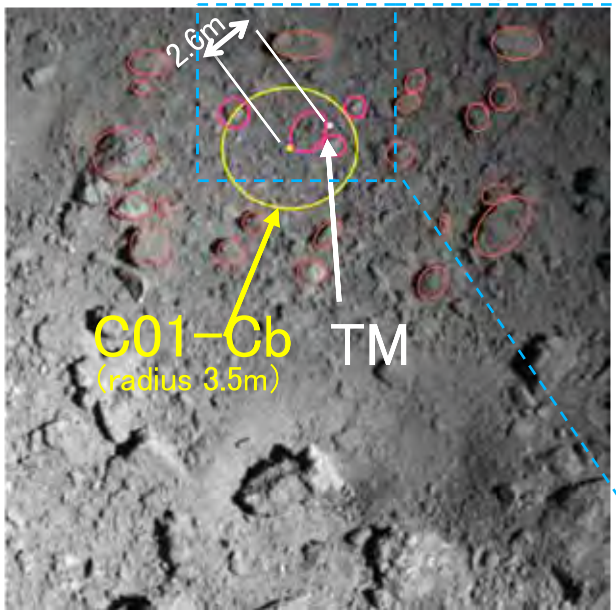
Images from the small monitor camera (CAM-H).
Images before and after touchdown (10x animation)

Capture time:
2019/7/11
Start 10:03:54 (altitude 8.5m)
Finish 10:11:44 (altitude 150m)
※image interval between 0.5s~5s

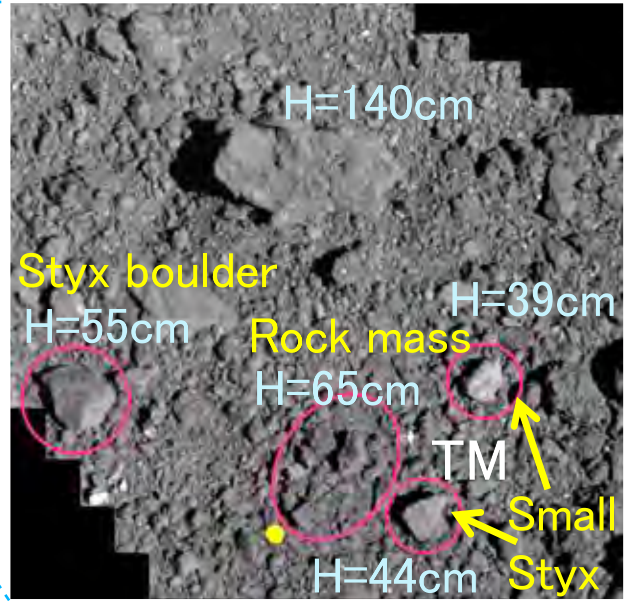
(credit:JAXA)

2. The 2nd touchdown operation

PPTD-TM1 image



PPTD-TM1B image

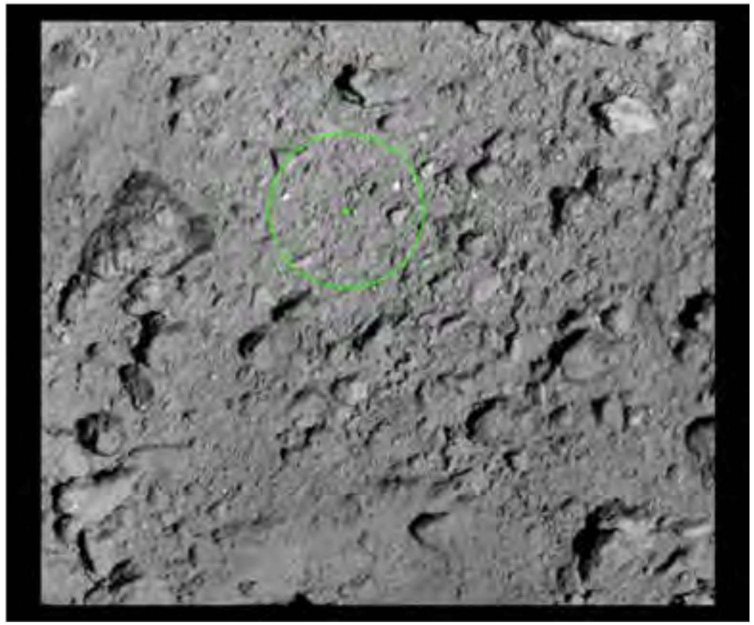


TM ＝ target marker
（The left-hand image is taken prior to dropping the TM and its position is marked. In the middle image, the TM itself is captured.）

H is the maximum estimated height
※ boulder names are nicknames, not official designations.

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

（animation）



DEM（Digital Elevation Map）near the touchdown candidate point

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

2. The 2nd touchdown operation

Challenges for the 2nd touchdown (difference from the 1st)

① Due to the optical system on the wide-angle Optical Navigation Camera ONC-W1 becoming cloudy, it was necessary to lower the starting altitude for capturing and tracking the TM (45m to 30m)
→ For the TM to be in the narrowed field of view of the ONC-W1, the accuracy of the GCP-NAV guidance had to be high.
→ Managed with the accuracy of the GCP-NAV guidance results

② The TM brightness decreased due to the cloudiness of the optical system of the ONC-W1.
→ High probability of a bright spot other than the TM being misjudged as the TM
→ Managed by changing the TM threshold recognition time

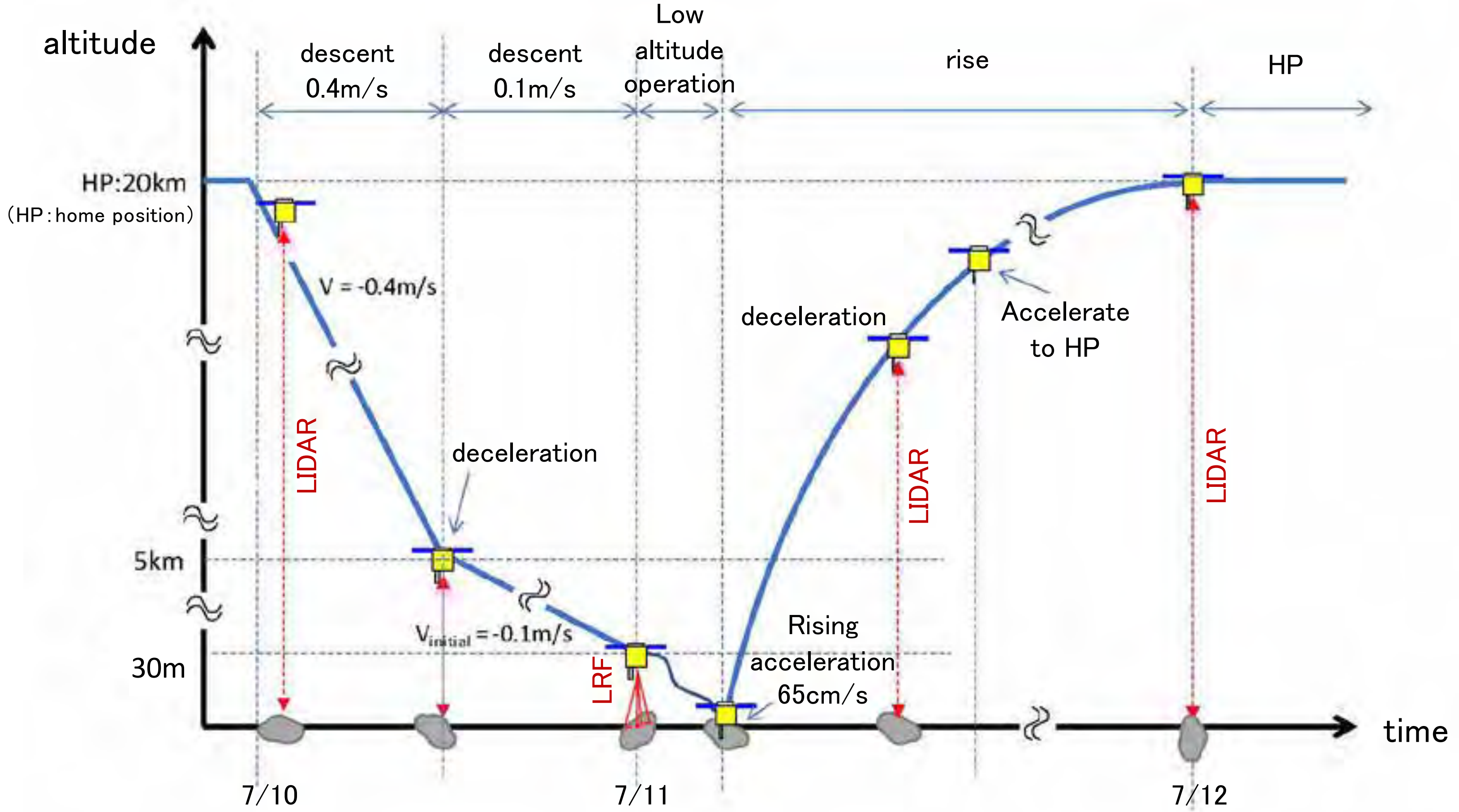
③ LRF measurable distance decreased due to the cloudiness of the LRF optical system.
→ Starting altitude for LRF use was lower (17m) than for the first touchdown (28m).
The descent sequence was therefore shifted to a lower altitude and it was necessary to devise safety measures for the spacecraft.
→ Timeout was applied.

④ Distance measurement error increased due to the cloudiness of the LRF optical system.
→ Since the range error was predictable, on-board software could correct the range value.
→ As a result, there was no issue with the LRF range accuracy.

TM：target marker
GCP-NAV（Ground Control Point Navigation) →method to find the position and velocity of the spacecraft through observing features on the asteroid surface.
LRF：Laser Range Finder

2. The 2nd touchdown operation

Operation sequence (overall)

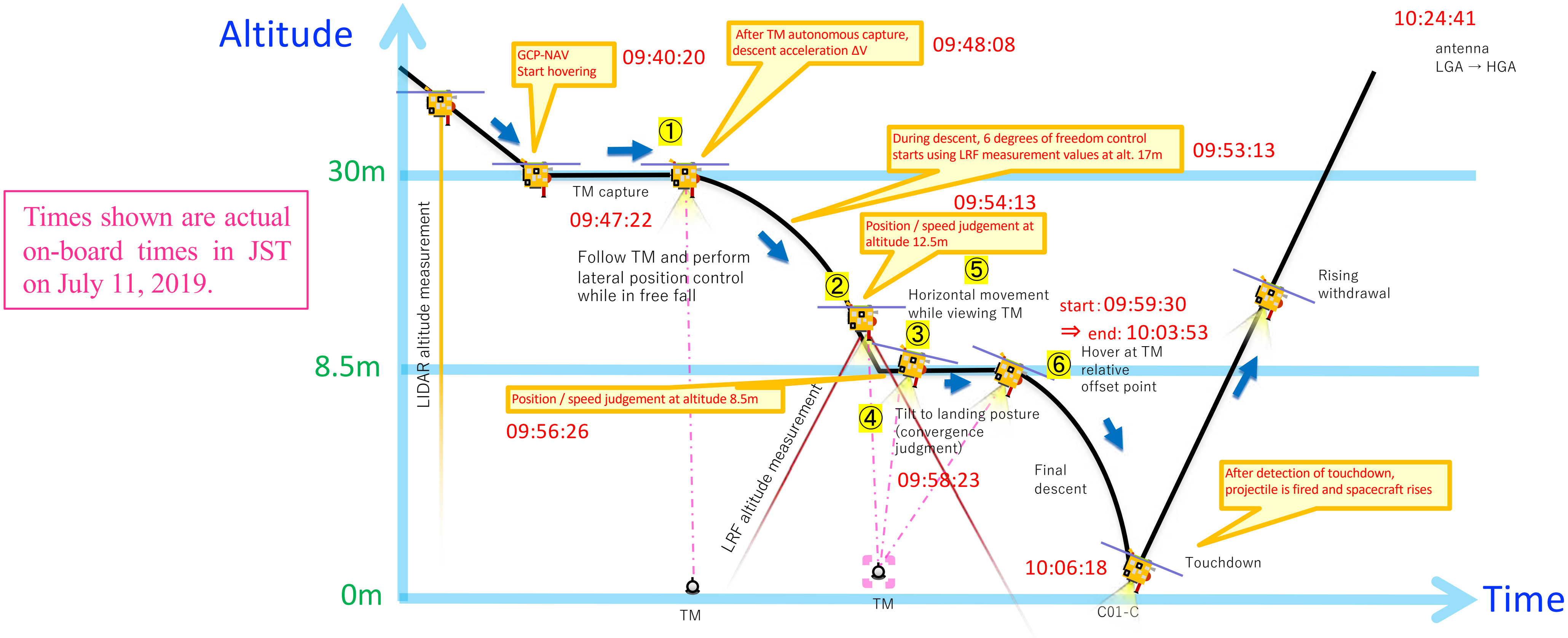


Date & time					
On-board time	10:46	21:06	09:40	10:06	
Ground time	11:00	21:20	09:54	10:20	

(image credit：JAXA)

2. The 2nd touchdown operation

Operation sequence (low altitude)



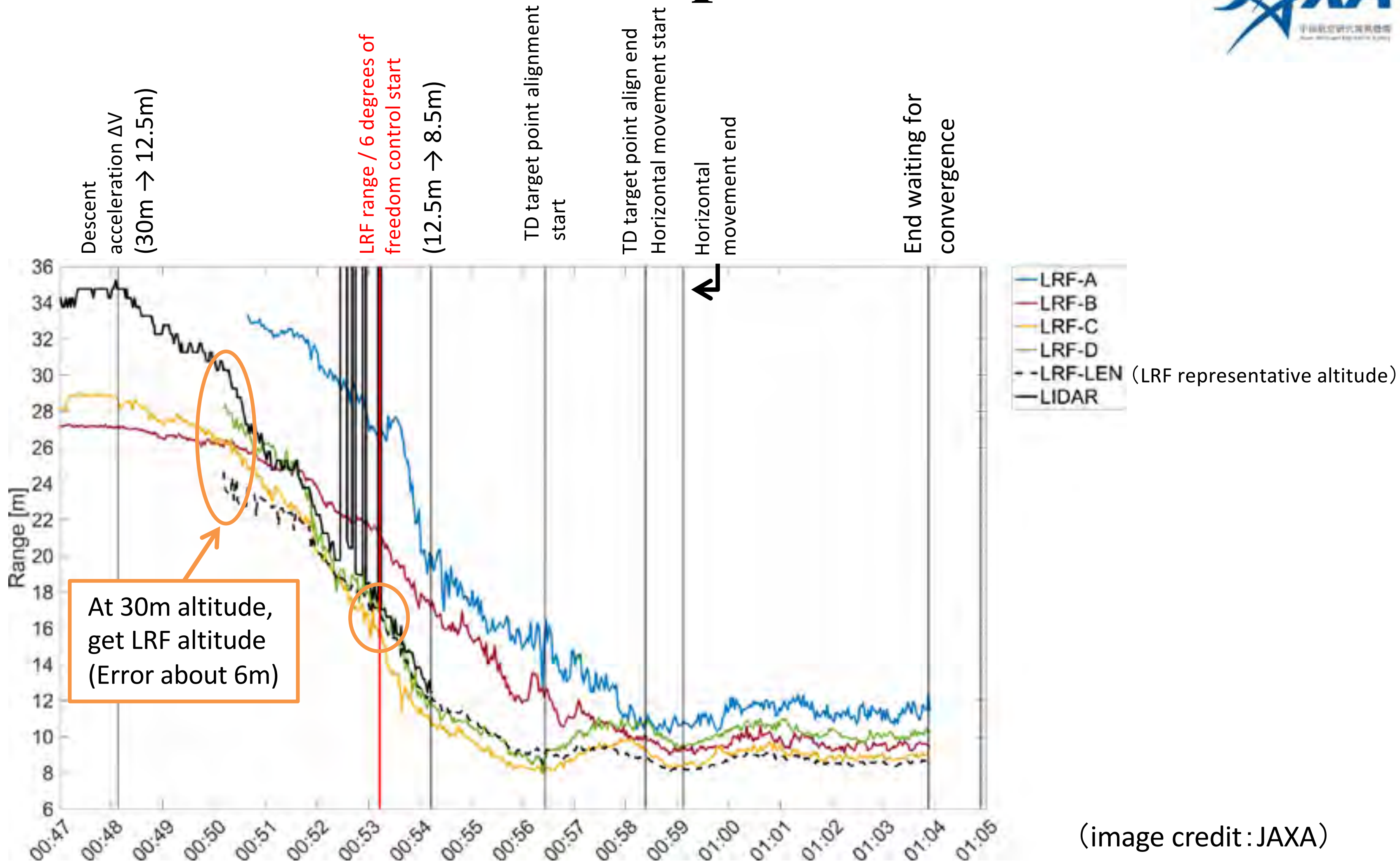
※①～⑥ checkpoints for autonomous judgements as to whether Hayabusa2 continues to the next sequence. （credit: JAXA）

2. The 2nd touchdown operation

item	Ground time: JST () onboard time	Decision item
Gate 1	7/10 09:58	Decision made on start of descent (@20km)
Gate 2	7/10 21:36	End of confirmation on whether to continue descent（@5km)
Gate 3	7/11 09:04	End of final descent judgement（GO/NOGO judgement)
HGA→LGA	7/11 10:01 (09:47)	Antenna switching
Gate 4	7/11 10:01	End of confirmation on switching to LGA
TD2	7/11 10:20 (10:06)	Touchdown
LGA→HGA	7/11 10:39 (10:25)	Antenna switching
Gate 5	7/11 11:10	End check of the state of the spacecraft
Gate 6	7/11 14:46	Judgement on return to home position
	7/12 10:50（10:37)	Return to home position

2. The 2nd touchdown operation

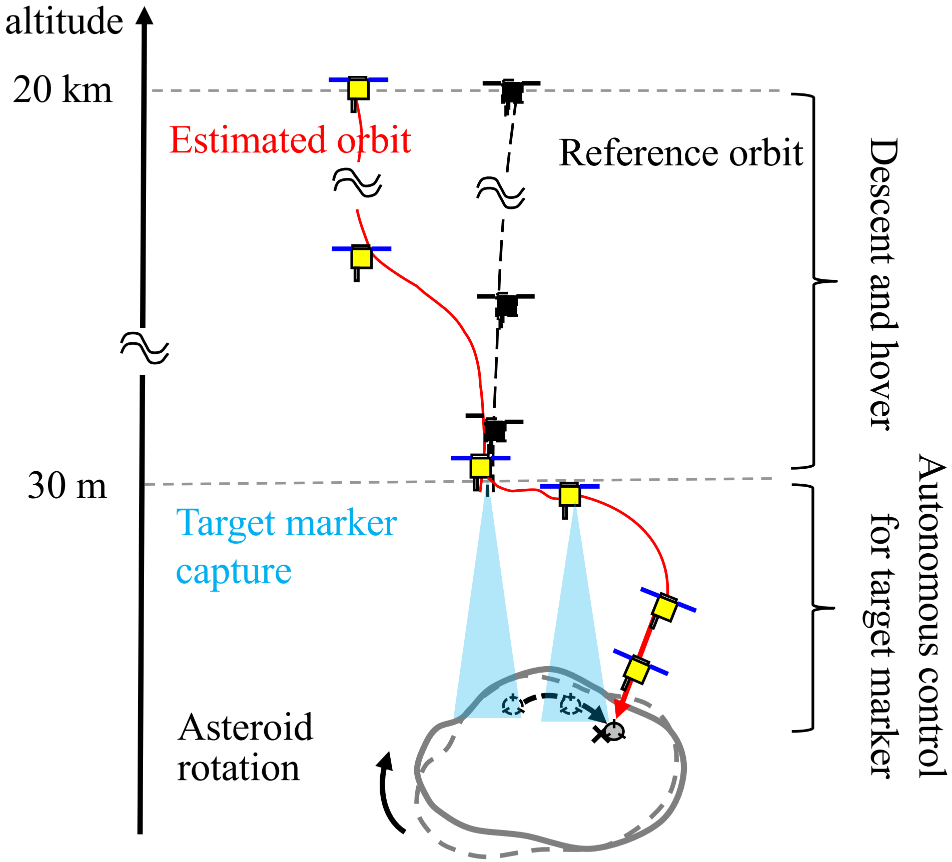
Flight data
LIDAR/LRF
history

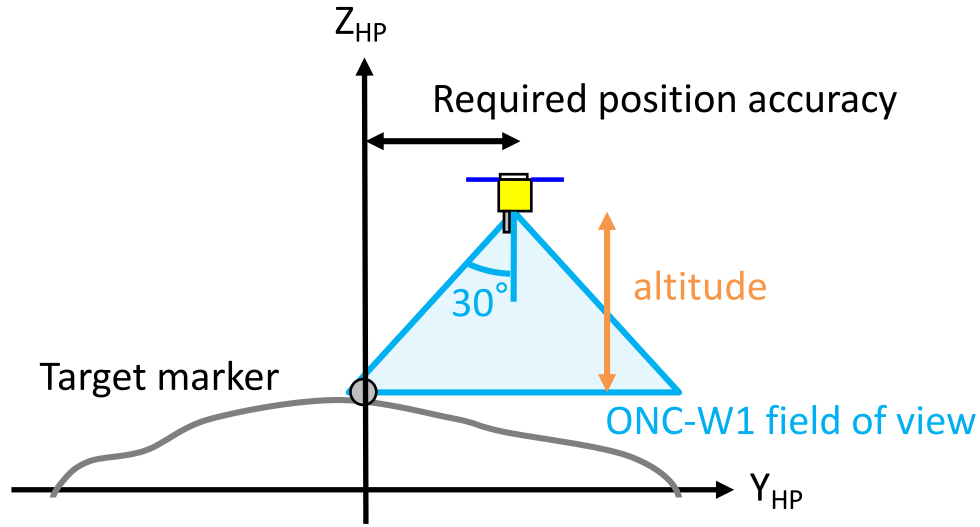


（image credit：JAXA）

2. The 2nd touchdown operation

Position accuracy required for target marker capture

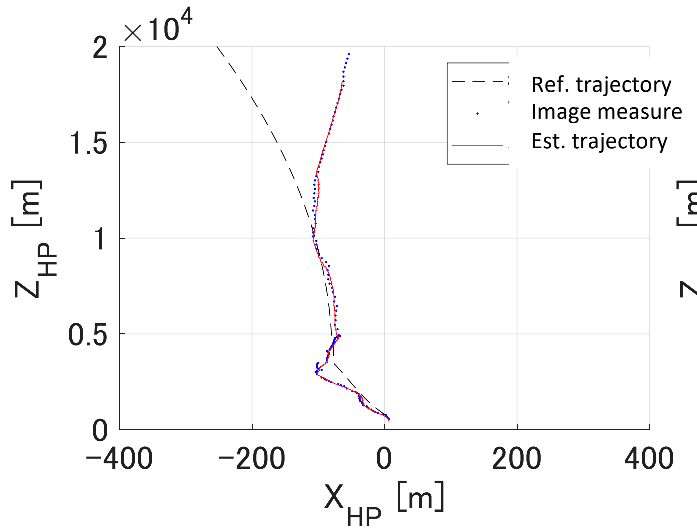


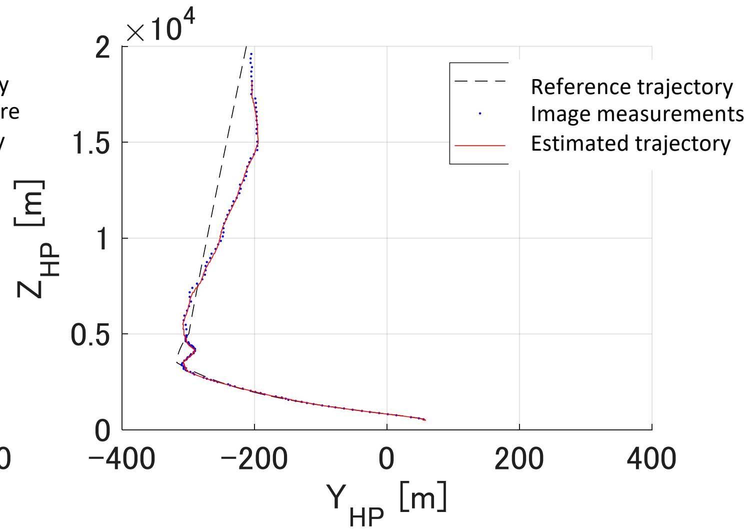


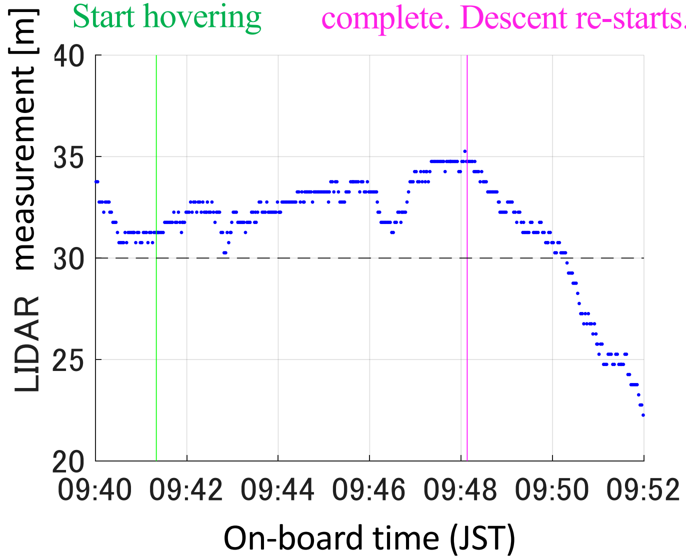
Alt.	Required position accuracy	Remarks
30 m	tan(30°)*30 = 17 m	When the altitude is as planned
20 m	tan(30°)*20 = 11 m	When altitude is 10m lower

2. The 2nd touchdown operation

Result（descent orbit・hovering altitude）







Final position error in the horizontal direction (X, Y, direction) is estimated to be 3m or less, and the final position error in the altitude (Z direction) is 5m or less. Target marker capture was successful.

2. The 2nd touchdown operation

Countermeasures for decline in camera light reception performance & target marker tracking

The 1st touchdown in February reduced the light reception performance for the Optical Navigation Camera (ONC-W1).

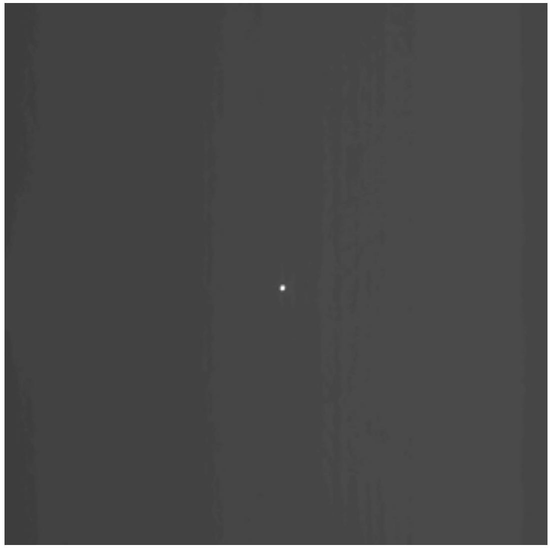
→To capture and track the target marker safely and reliably at low altitudes, the image processing parameters (threshold value for digitizing the image into two graduations of black and white) were adjusted.

This step makes it possible to recognize even darker target markers, but also makes it easier to mistake floats (such as dust) around the spacecraft, or bright rocks on the ground, for target markers.

→Using images acquired during past operations, the perceived motion of a target marker versus floating and similar objects is determined, as well as other identifying parameters (such as the threshold for the time needed to capture the target marker, given the movement between previous and subsequent frames), the size of the target area etc.

→During the actual mission, the target marker could be tracked stably even in the presence of floats.

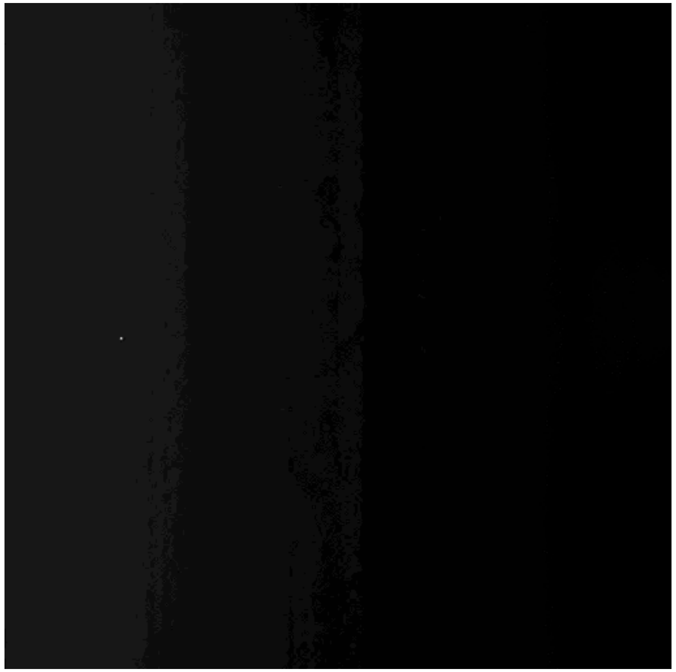
Target marker image during tracking at an altitude of 8.5m
（Brightness adjusted on the ground）



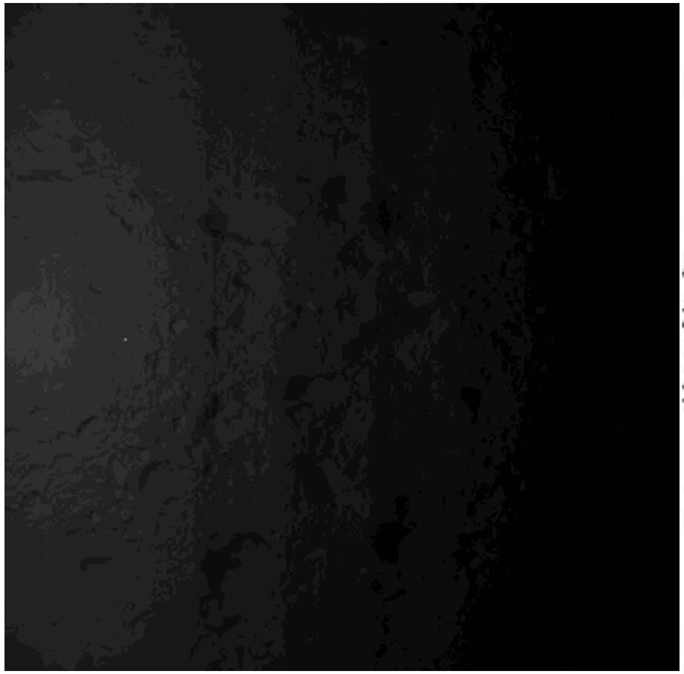
（image credit：JAXA）

2. The 2nd touchdown operation

DBT/NBT image and target marker tracking

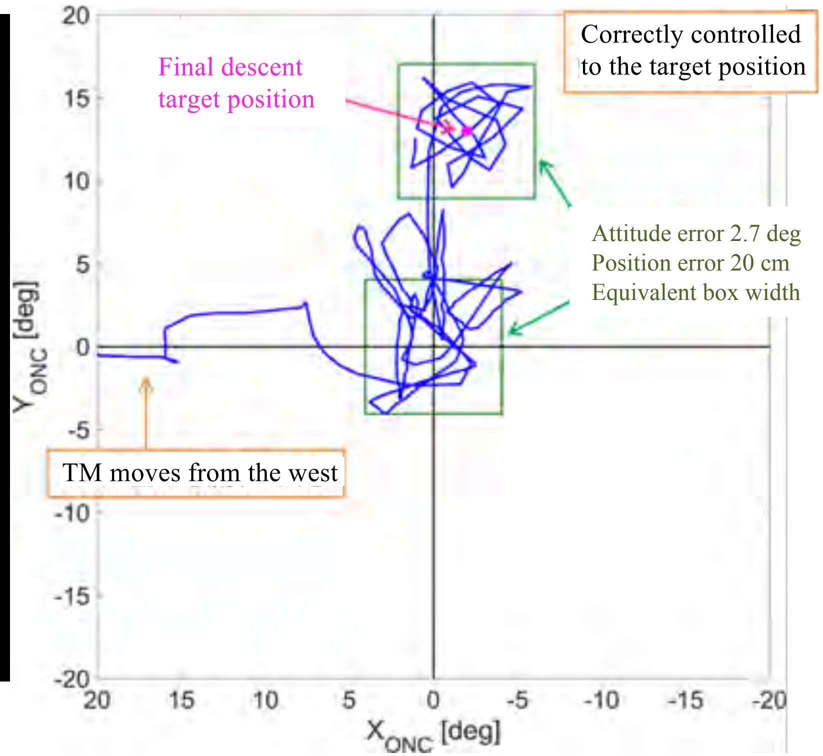


DBT (Differential Bright object Tracking)
: image actually used by the spacecraft for measurement



NBT (Normal Bright object Tracking)
: similar image not used for actual measurement (reference)

（Video：20x）

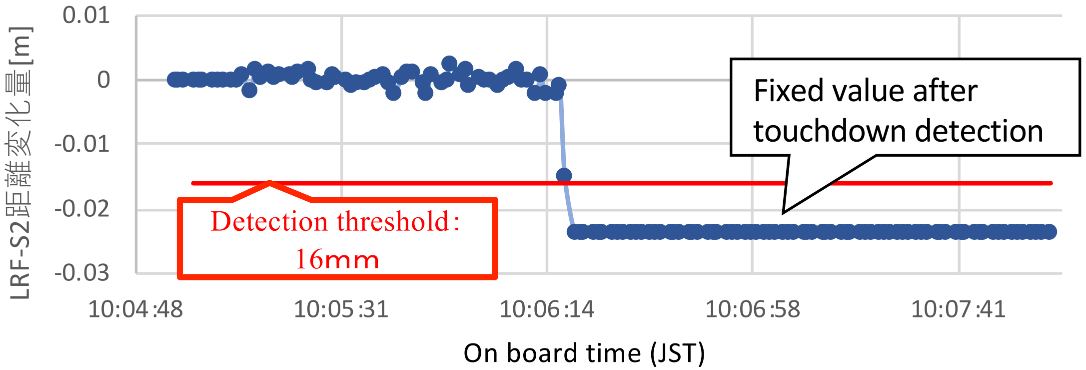


（credit：JAXA）

2. The 2nd touchdown operation

Final descent below 8.5m & touchdown of the spacecraft

- The final descent ΔV for touchdown was performed at an altitude of 8.5m. Touchdown detection was enabled 50 seconds after the final descent ΔV. Then touchdown occurred on the asteroid surface. Touchdown was judged by detecting the change in distance with the LRF-S2, which measures the distance to the tip of the sampler horn that compresses slightly during touchdown.
- After touchdown detection, the sequence for firing a 3rd projectile, followed by the sampling sequences, were performed. An ascending ΔV then caused the spacecraft to rise and leave the asteroid surface.
- As vibration in the sampler horn is generated by the final descent ΔV, the sequence was devised so as not to generate unnecessary sampler horn vibration.
- At the time of touchdown, the 'tail-up' posture is adopted around the Y-axis to prevent collision of the spacecraft with the boulders and other protrusions, based on the prediction of the spacecraft behaviour.



LRF-S2 measurements before and after touchdown detection

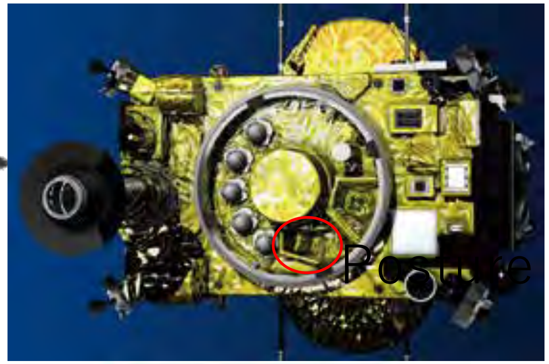
Operation sequence from final descent

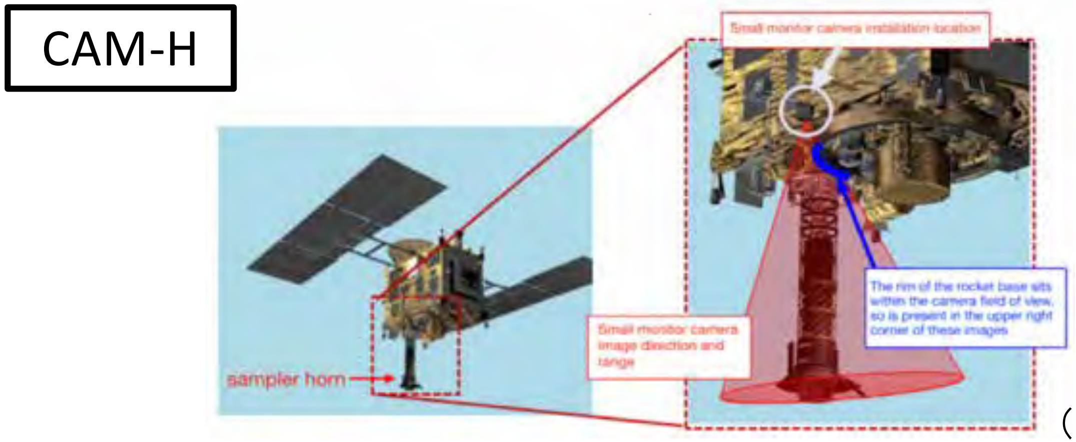
Time (s)	On-board time (JST)	Event
-60		Final altitude control begins
0	10:04:55	Final descent ΔV begins
15		RW attitude control beings （sampler horn vibration prevention measures）
50		Touchdown detection judgement begins
~70		Posture convergence
82-84	10:06:17-19	Touchdown detection
82-84	10:06:17-19	Sampling operation （Projectile launch etc.）
82-84	10:06:17-19	Rising ΔV begin
94		RCS attitude control transition

（image credit：JAXA）

2. The 2nd touchdown operation

- The LRF-S2 emits a laser towards a reflector attached to the tip of the sampler horn.
- This measures distance and intensity value.





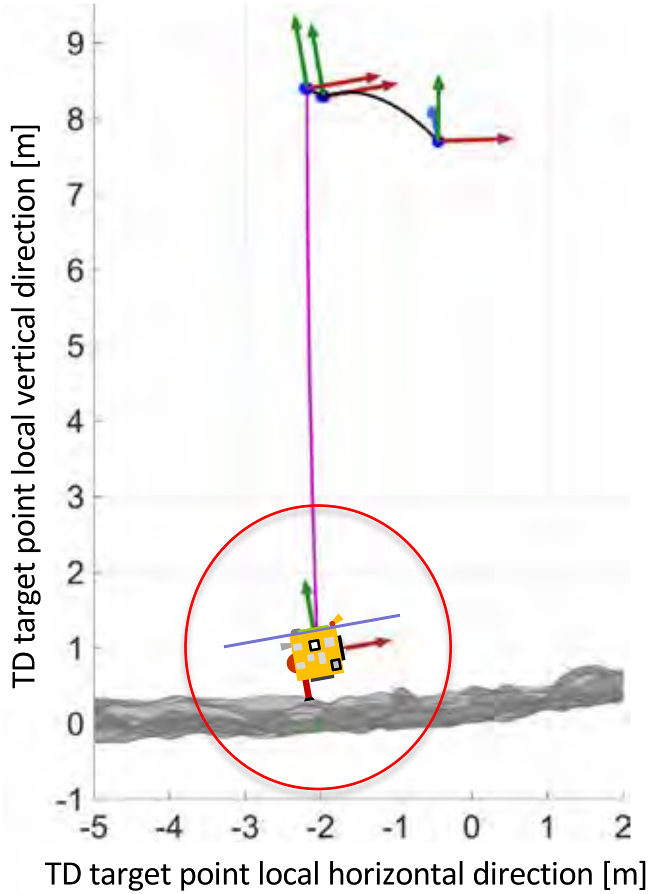
Laser light from the LRF-S2 imaged by CAM-H
(At the 2nd touchdown)

(Image credit：JAXA)

2. The 2nd touchdown operation

Final descent below 8.5m & touchdown of the spacecraft

- During the 2nd touchdown, the tail-up posture was adopted to prevent contact between boulders and other obstructions with the spacecraft.
- During tail-up, in addition to the spacecraft posture aligning to the terrain surface, the posture is rotated by 10 degrees about the Y-axis of the spacecraft to give the target attitude for touchdown.



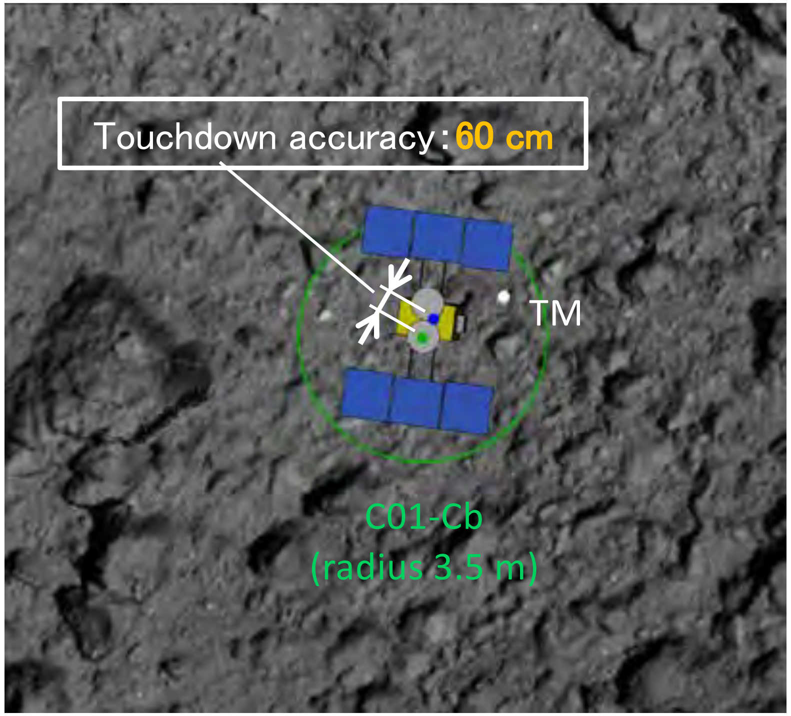
（Image credit：JAXA）

Nominal touchdown attitude during operation plans

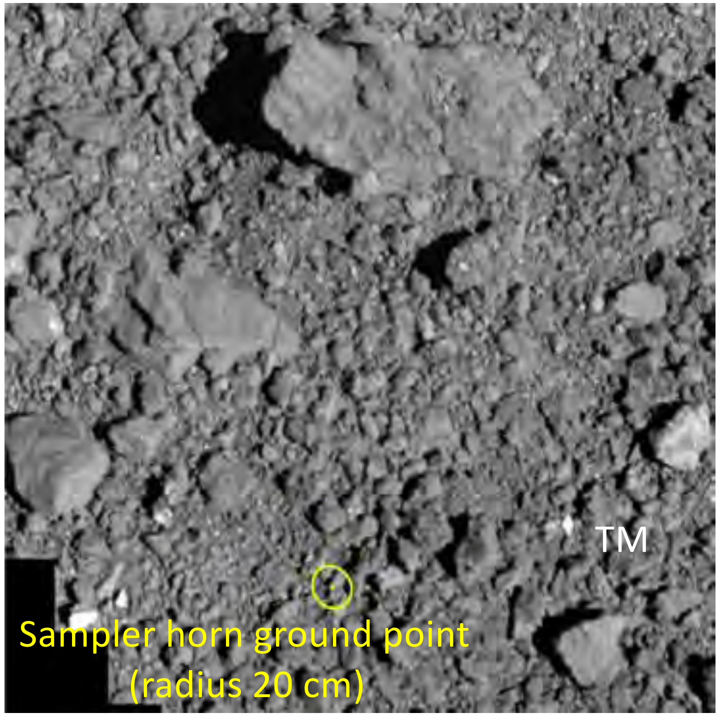
2. The 2nd touchdown operation

2nd touchdown accuracy and sampler horn ground point

2nd touchdown accuracy



Sampler horn ground point



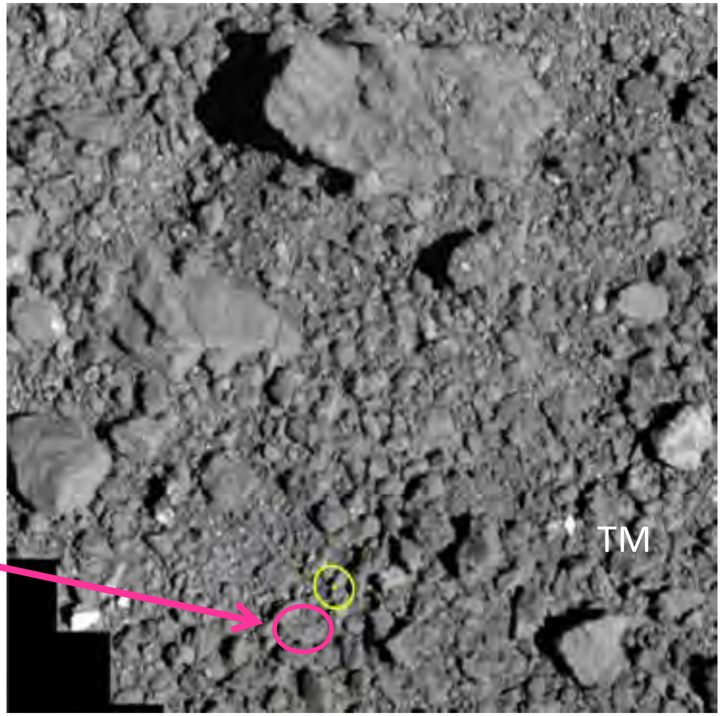
(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)

2. The 2nd touchdown operation

2nd touchdown sampler horn ground point

Sampler horn ground point

CAM-H images



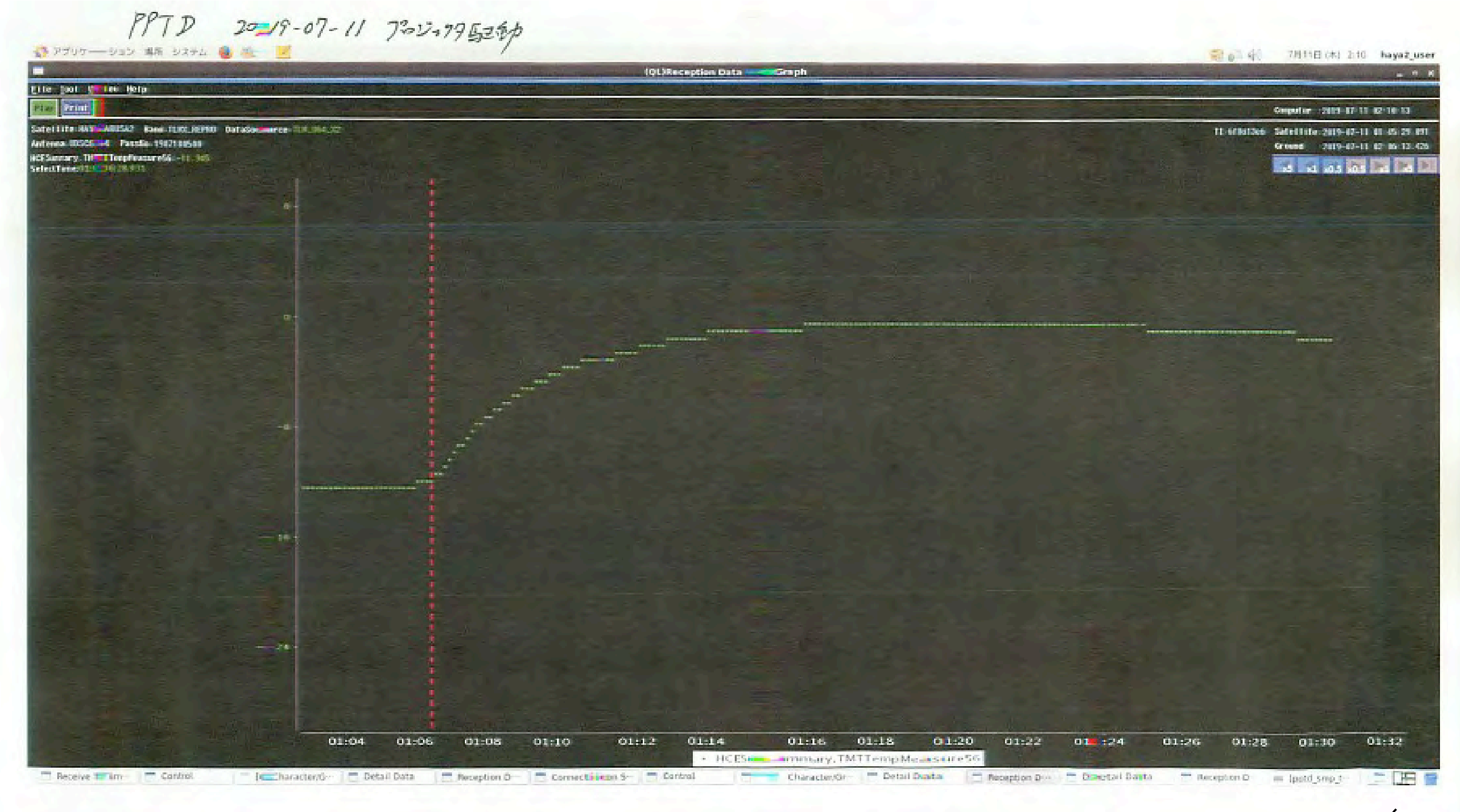
Consistent with CAM-H image

(Image credit：JAXA)

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

2. The 2nd touchdown operation

Projector temperature change

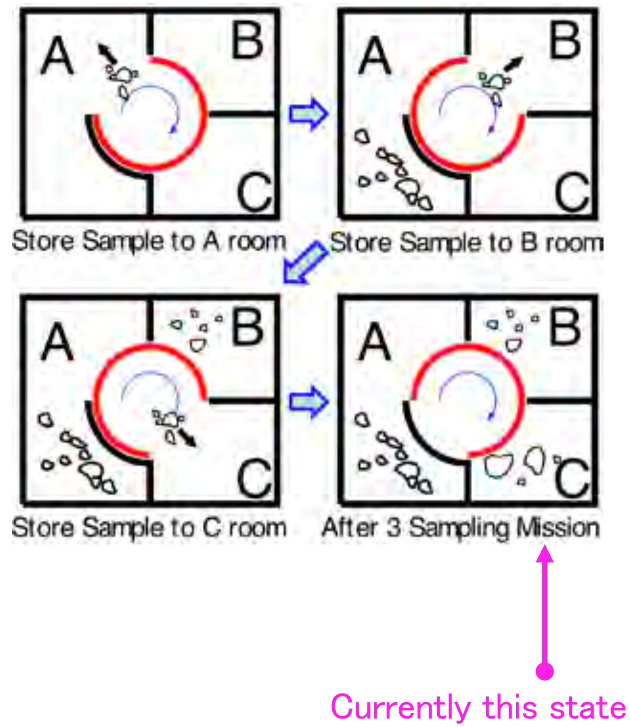


(Image credit：JAXA)

2. The 2nd touchdown operation

Closing the catcher chamber

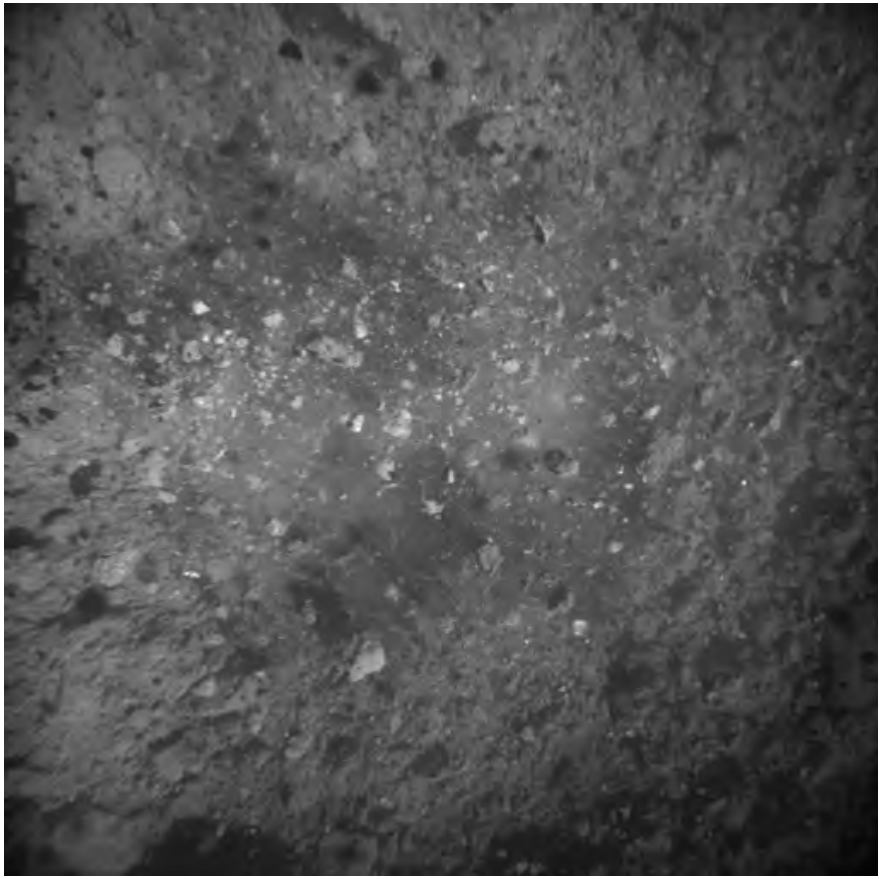
- Chamber A closed immediately after the 1st touchdown (February 22).
- Chamber B was open after this, but closed in an operation on June 24. (A total of 7 descent operations were conducted while chamber B was open).
- Chamber C was then open but closed after the 2nd touchdown on July 11 at 14:10 JST (onboard time). (The ascent speed was reduced by 2 cm/s at 13:40 JST so that any sample at the tip of the sampler horn would be collected).



(Image credit：JAXA)

3. Images from the 2nd touchdown

Images from the ONC-W1
Capture time:
  2019/7/11
  10:06:32 JST (on-board time)
Altitude: about 8m



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

3. Images from the 2nd touchdown

Images from the ONC-W1
Capture time:
  2019/7/11
  10:08:53 JST (on-board time)
Altitude: about 90m

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

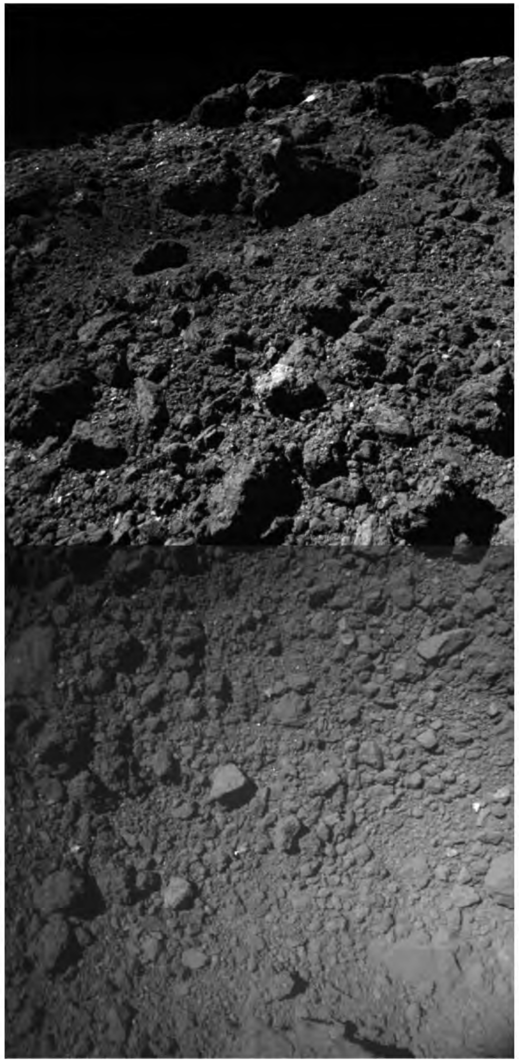
3. Images from the 2nd touchdown

First release

2nd touchdown ONC-W1/W2 composite panoramic image at an altitude of 8m during the final descent.

ONC-W2 2019/07/11 10:04:58 JST (onboard time)

ONC-W1 2019/07/11 10:04:57 JST (onboard time)

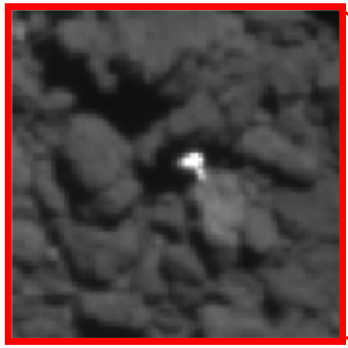


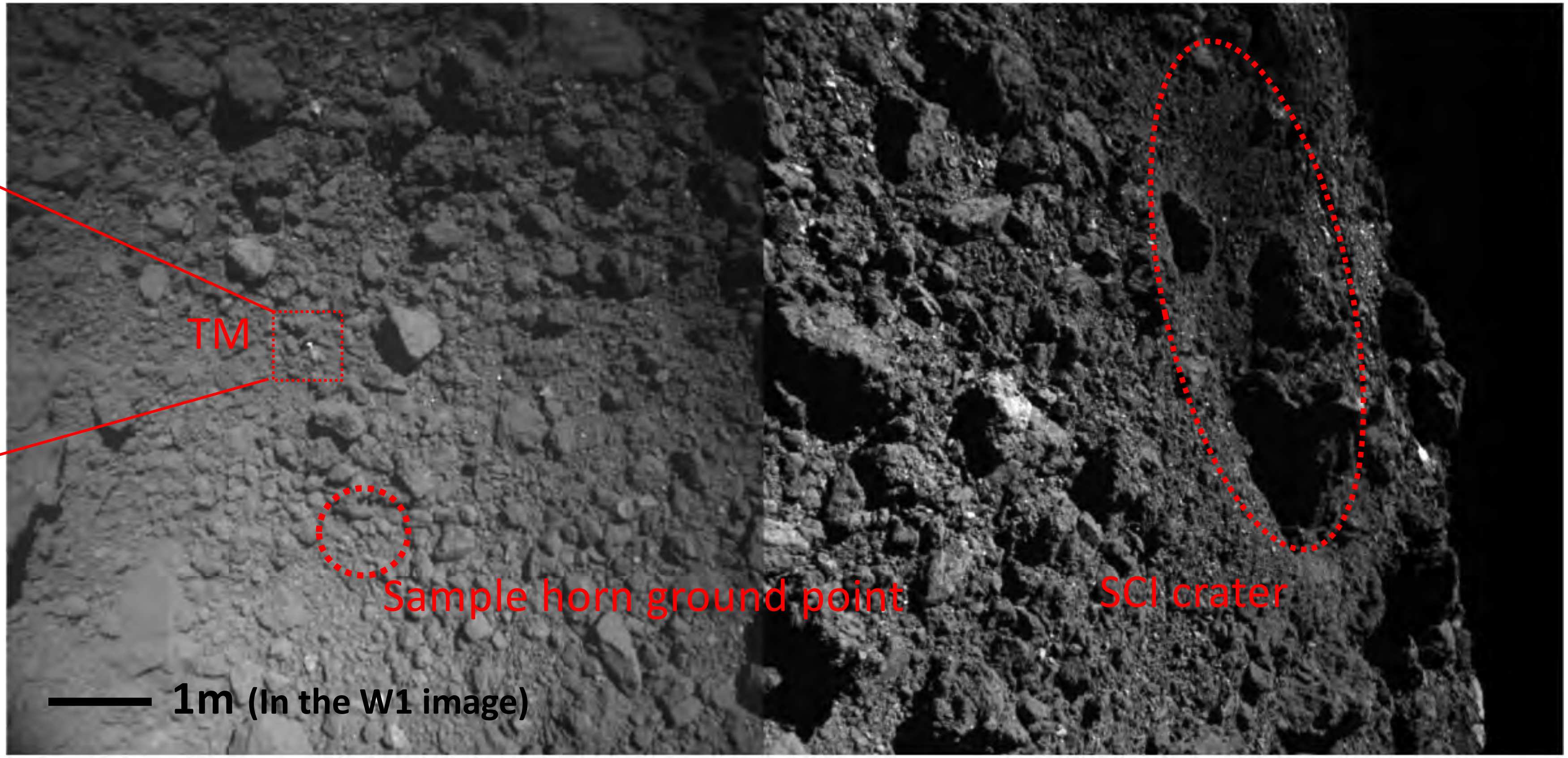
(Credit: JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Meiji University, University of Aizu, AIST)

3. Images from the 2nd touchdown

Explanation

2nd touchdown final descent ONC-W1/W2 composition panoramic image at 8m altitude



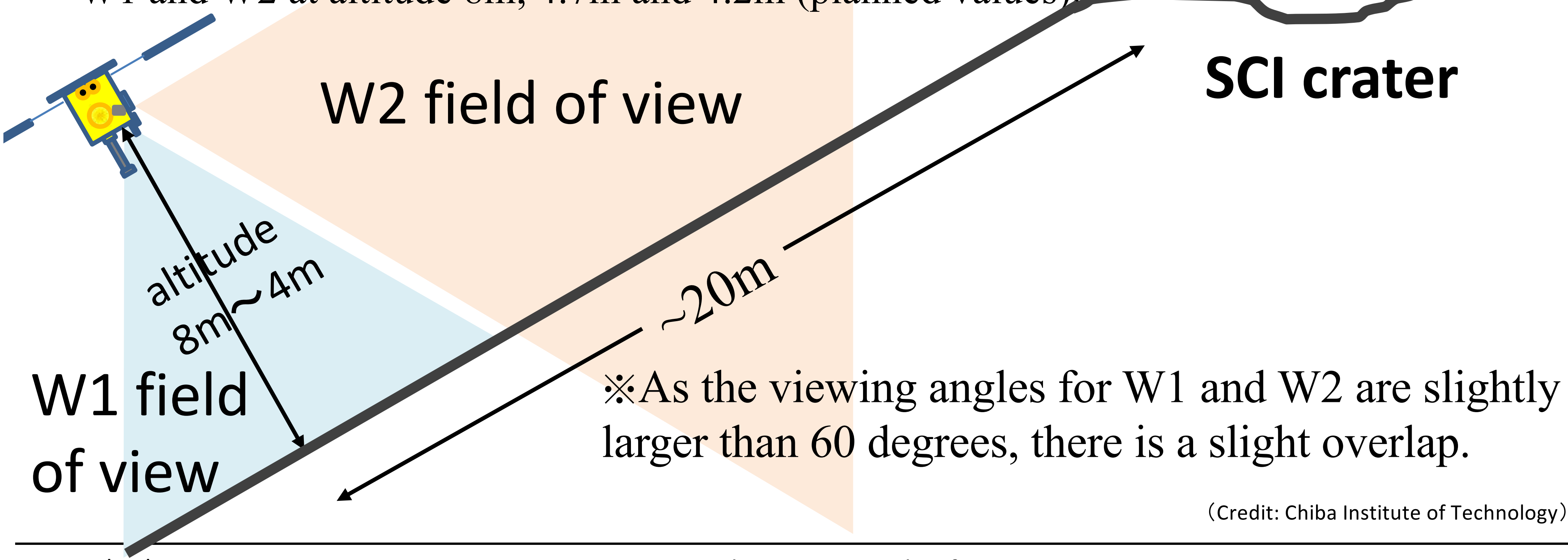


ONC-W1 2019/07/11 10:04:57 JST（onboard time） ONC-W2 2019/07/11 10:04:58 JST（onboard)

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

Reference: Geometrical relationship between W1/W2 imaging

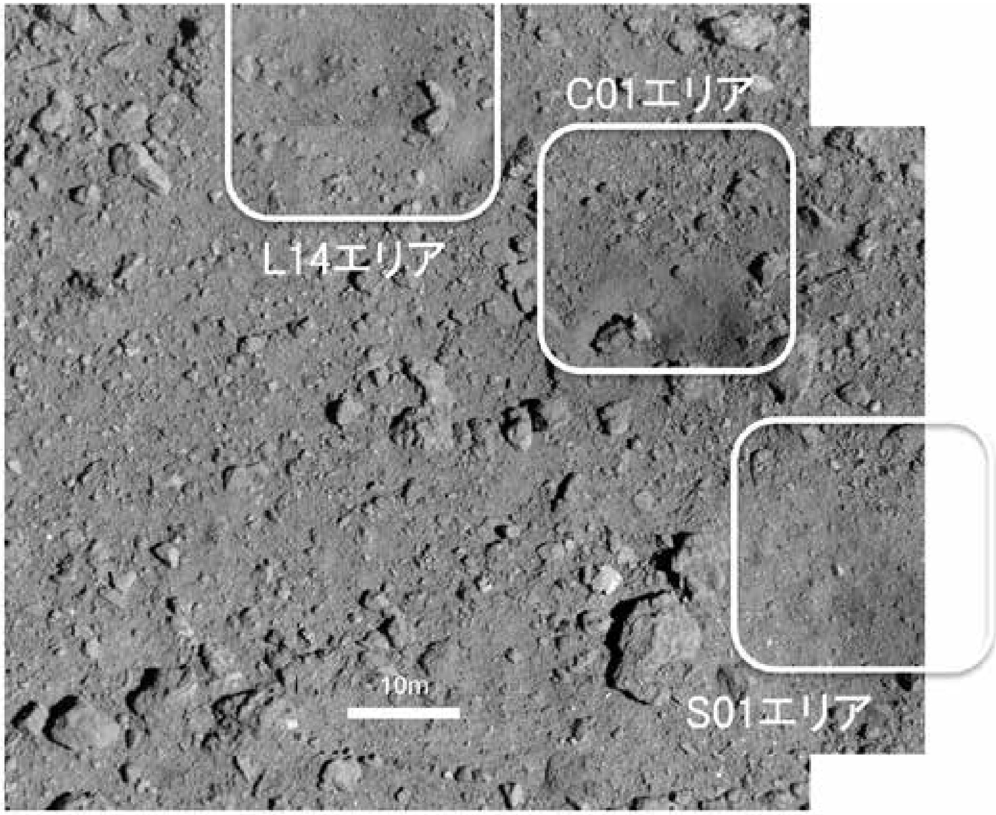
- ONC concentrates on TM image acquisition until the final descent at an altitude of 8.5m.
- After the final descent from an altitude of 8.5m, imaging was performed with the W1 and W2 at altitude 8m, 4.7m and 4.2m (planned values).



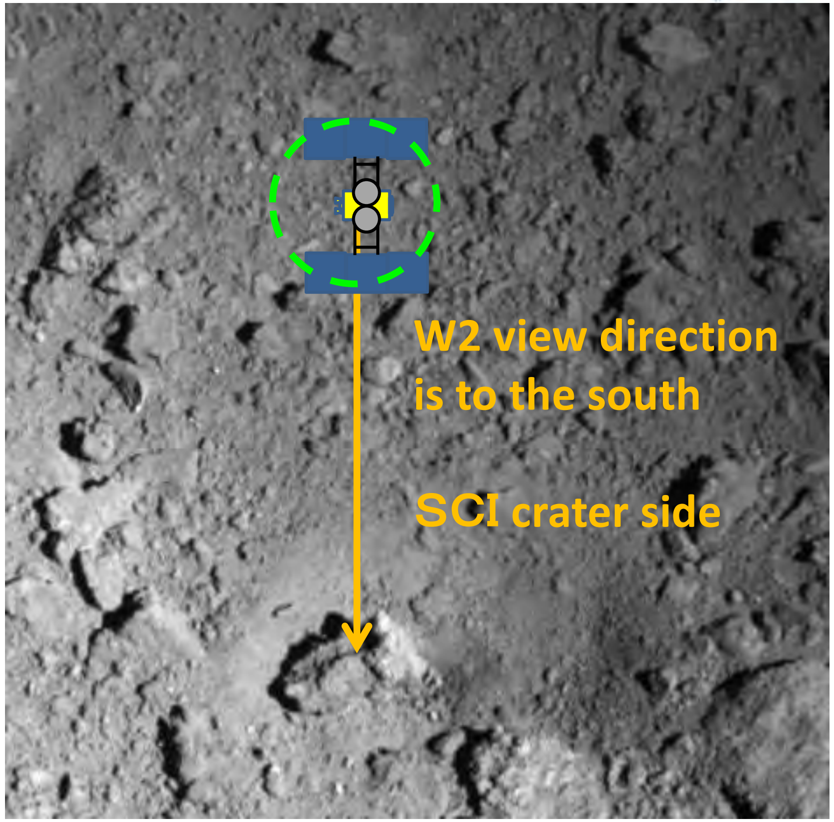
※As the viewing angles for W1 and W2 are slightly larger than 60 degrees, there is a slight overlap.

（Credit: Chiba Institute of Technology）

Reference: positional relationship about the C01 area



PPTD－TM1　2019/05/16
Images from an altitude ~0.5km and ~0.6km



PPTD－TM1

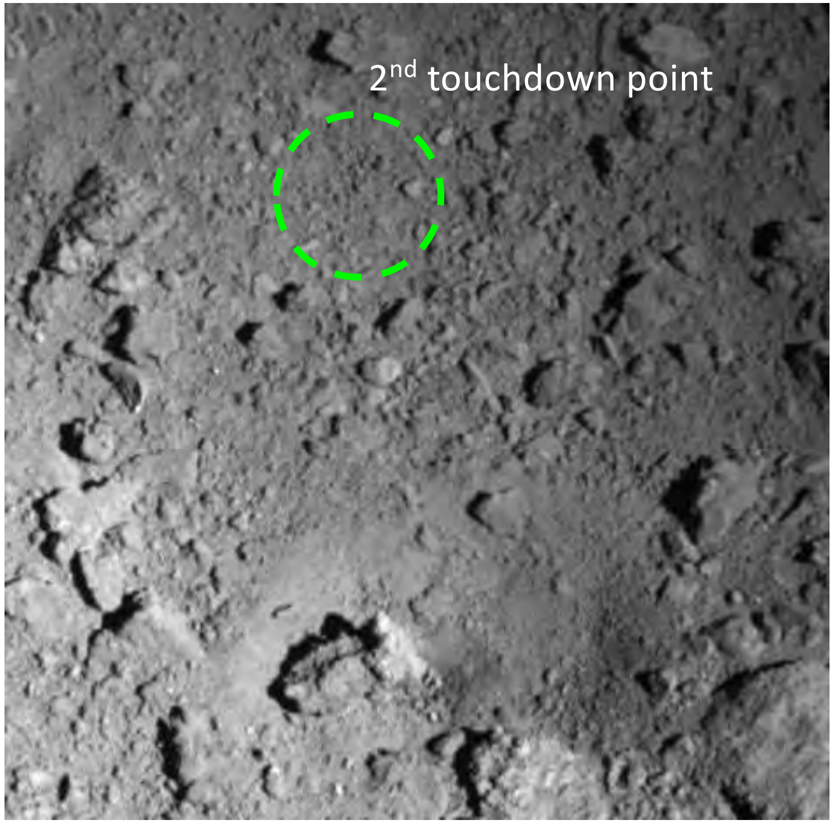
(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)

4. Name of the 2nd touchdown point

The name of the 2^{nd} touchdown point is:

Uchide-no-kozuchi

Meaning：In Japanese folklore, the uchide-no-kozuchi is a magic hammer that can produce great riches. The samples gathered from this site are expected to produce great scientific results.



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

5. Upcoming events

■Operation plans

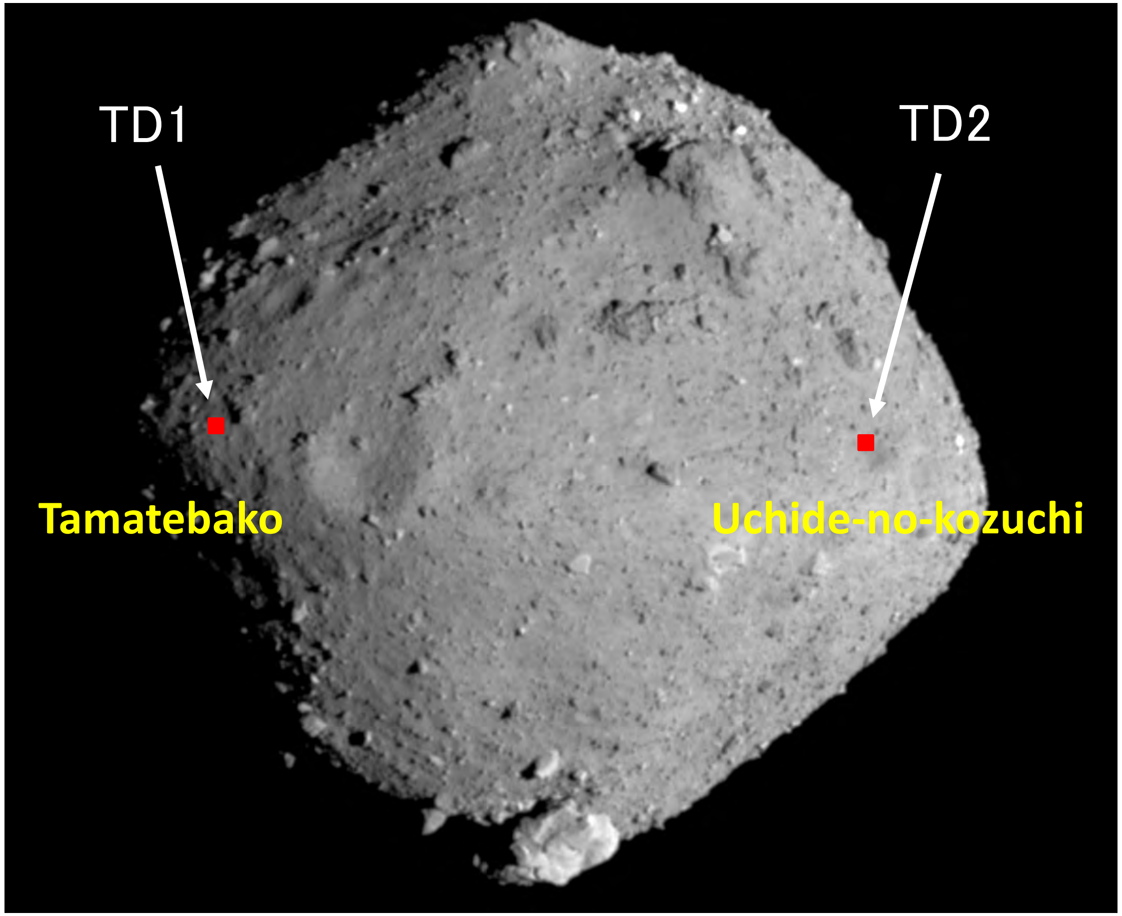
- BOX-C operation from July 20 – 31. The lowest altitude will be about 5km from July 25 – 27.

■Press and media briefings

- 8/22（Thursday）15:00～16:00 regular press briefings @ Tokyo office

Reference material

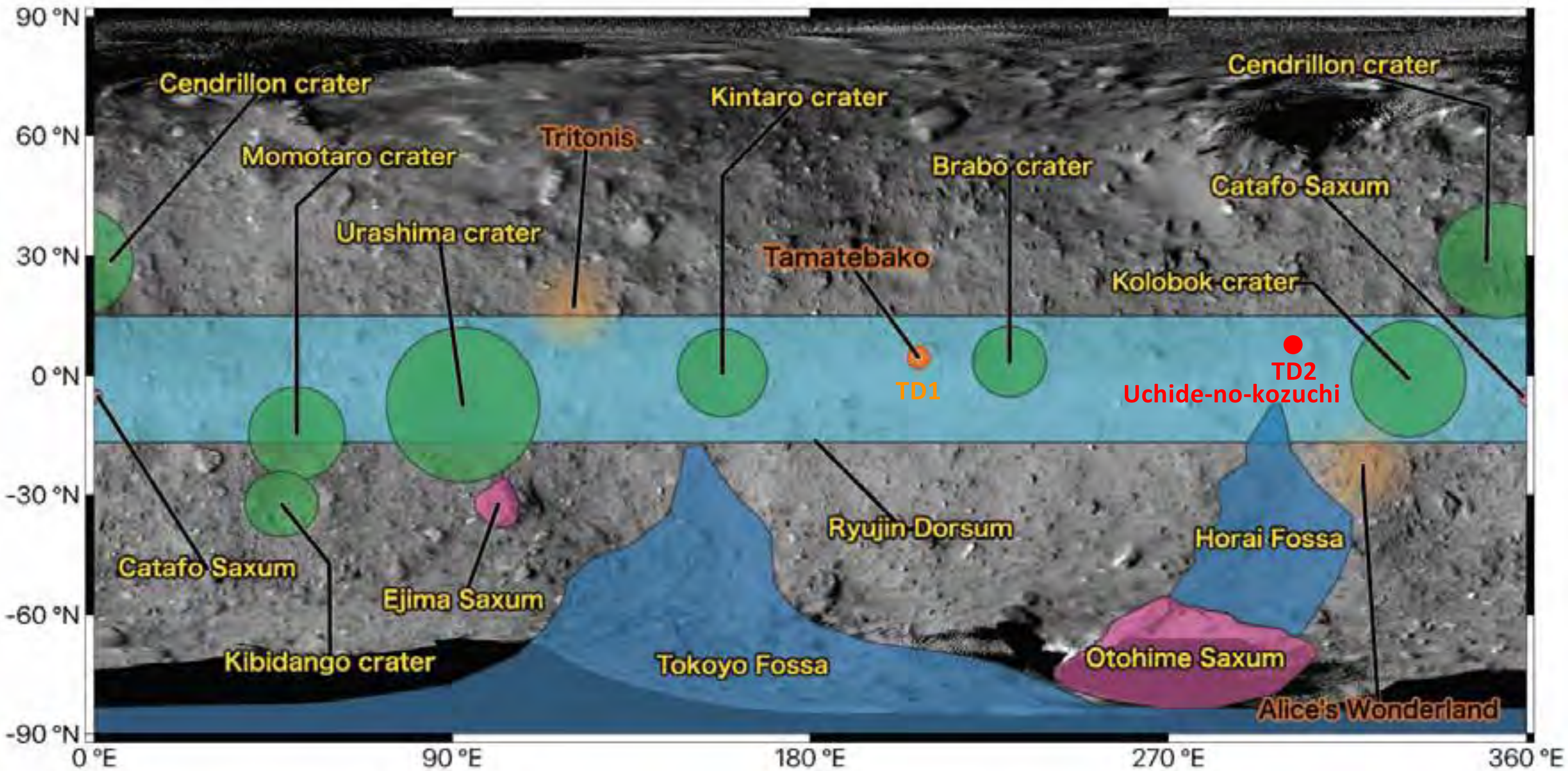
Locations for the 1st (TD1) and 2nd (TD2) touchdown



2019/5/20
Taken from the home position

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

Touchdown locations for the 1st (TD1) and 2nd (TD2) touchdown



Note: Tritonis (landing site for MINERVA-II1), Alice's Wonderland (MASCOT landing site), Tamatebako (first touchdown point) are nicknames and not recognised by the International Astronomical Union (IAU). Other places names are official names recognised by the IAU.

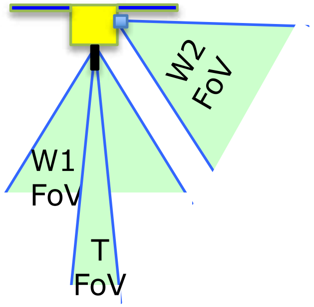
（image credit：JAXA）

Optical navigation camera (ONC)

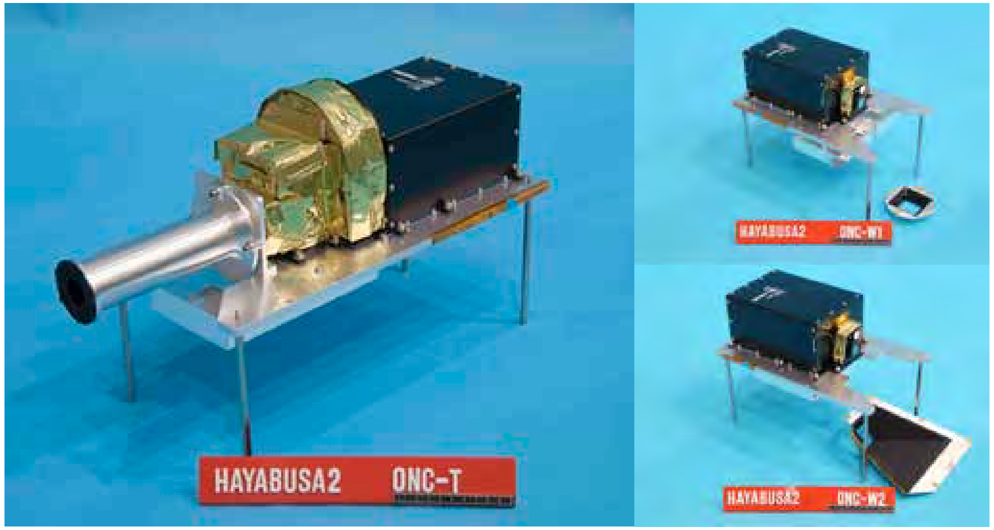
ONC：Optical Navigation Camera

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

Scientific measurements：
- Form 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 hydrous 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



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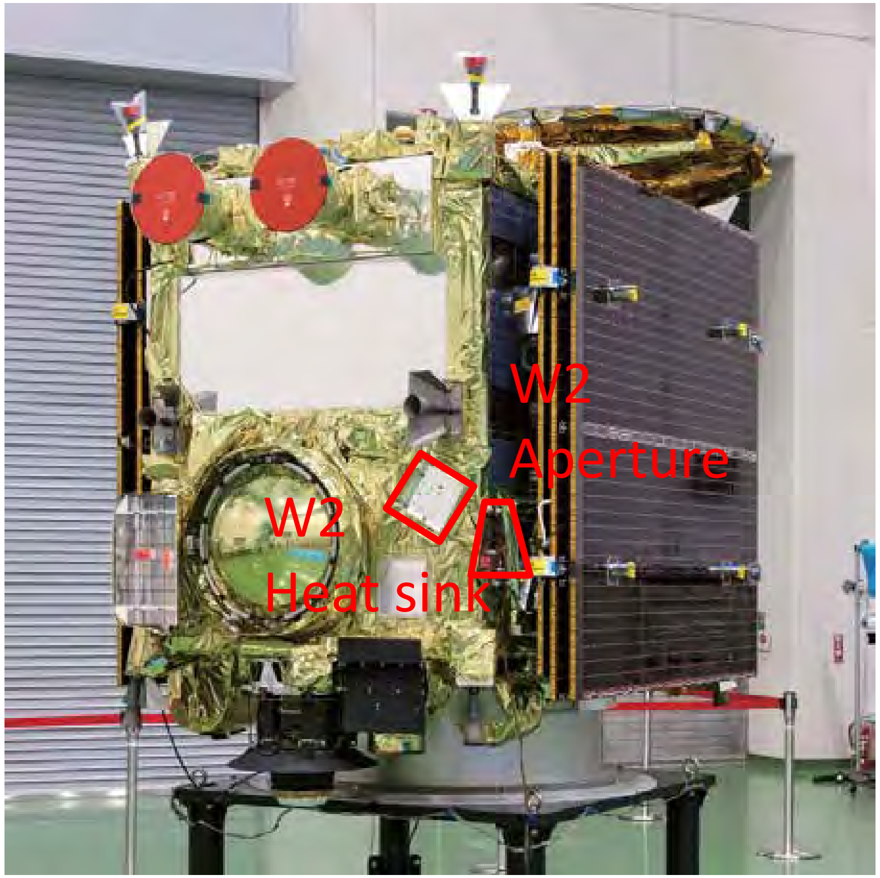
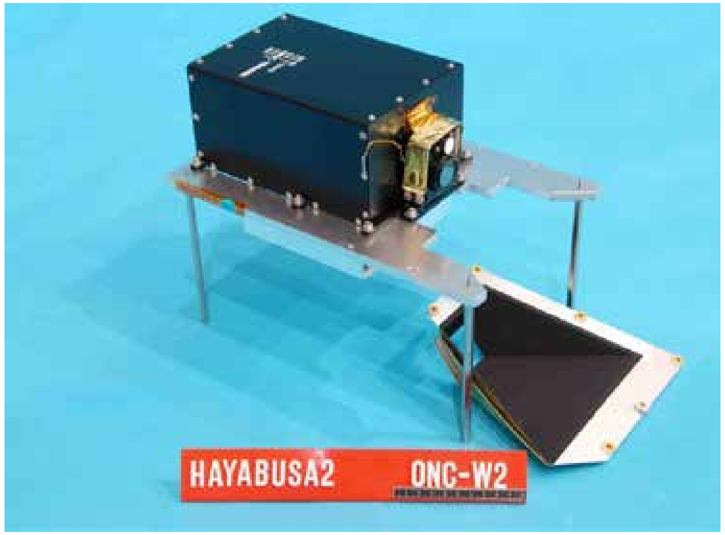
	ONC-T	ONC-W1	ONC-W2
Detector	2D Si-CCD (1024 × 1024 px)		
Viewing direction	Downward (telephoto)	Downward (wide-angle)	Sideward (wide-angle)
Viewing angle	6.35° × 6.35°	65.24° × 65.24°	
Focal length	100 m–∞	1 m–∞	
Spatial resolution	1 m/px @ 10-km alt. 1 cm/px @100-m alt.	10 m/px @10-km alt. 1 mm/px @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）