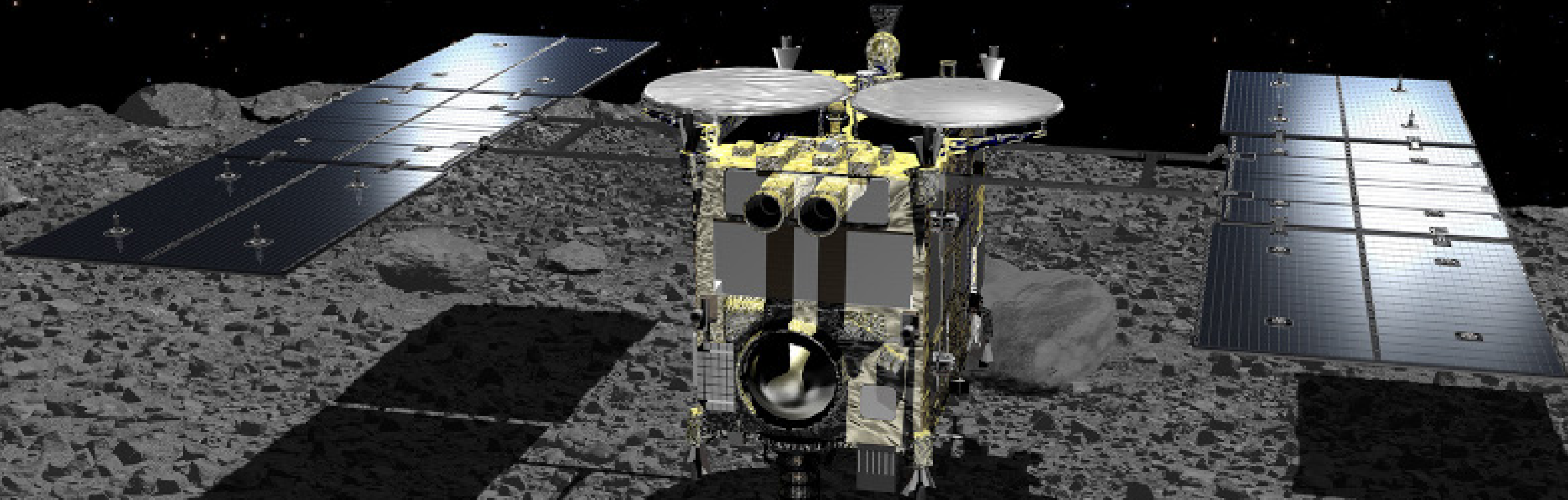
Asteroid Sample Return Mission Hayabusa2



AIAA LA-LV Planetary Defense and Asteroid Exploration e-mini-Conference 2020
June 27, 2020

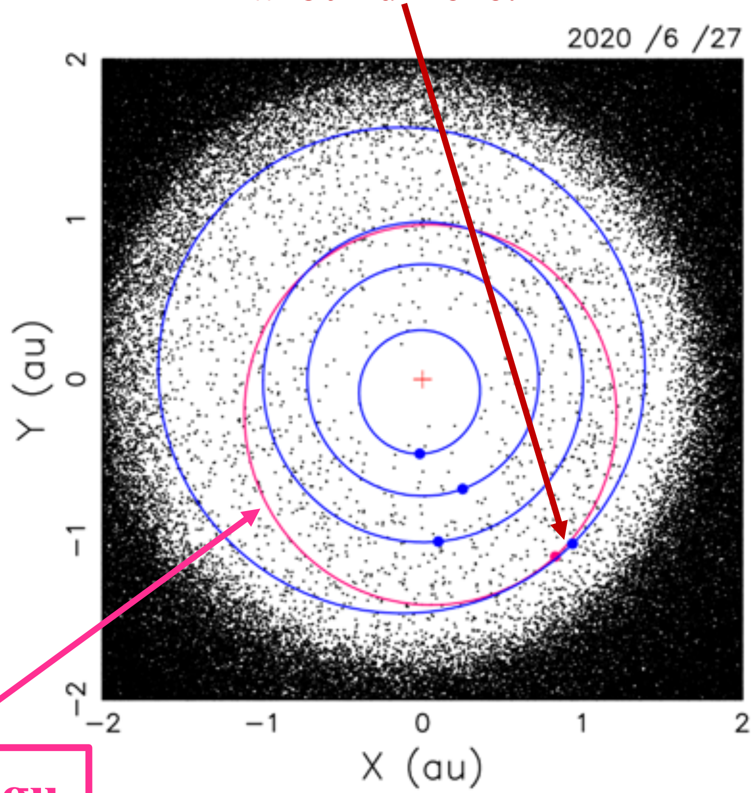
Hayabusa2

M. Yoshikawa and Hayabusa2 Project Team
Japan Aerospace Exploration Agency

Hayabusa2 mission

The second asteroid sample return mission

Hayabusa2 is around here.

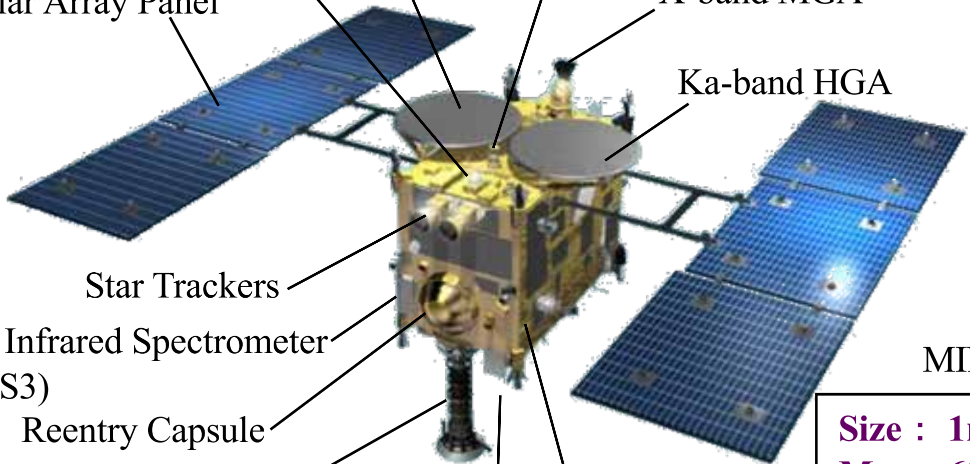


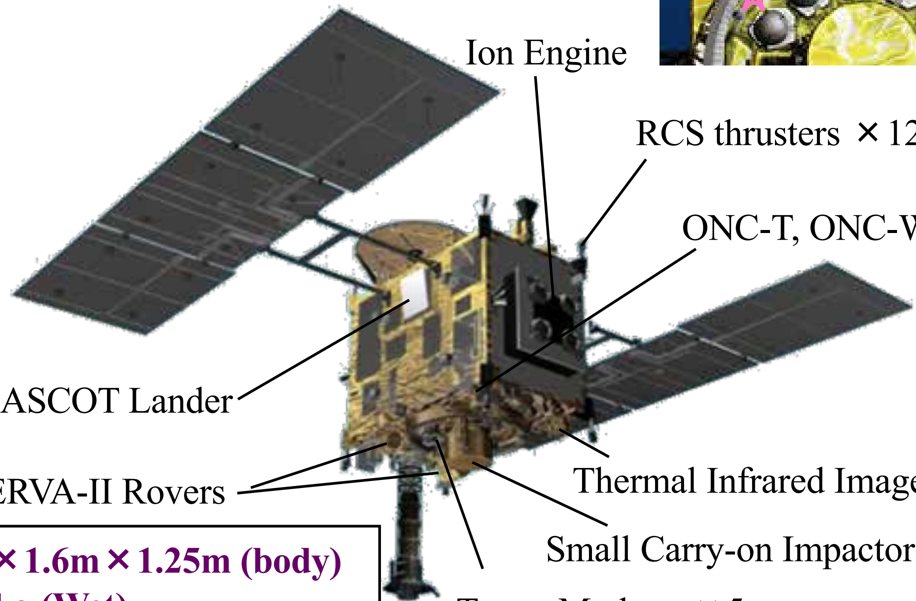
- The origin of the solar system
- Organic matters
- New technologies

(162173) Ryugu

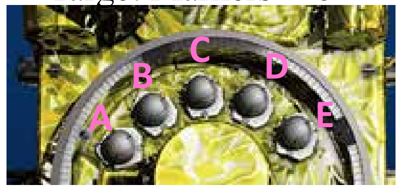
a small C-type NEO ⇨ important for planetary defense

Hayabusa2 Spacecraft





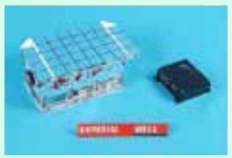
Target Markers ×5



Size： 1m×1.6m×1.25m (body)
Mass： 609kg (Wet)

ONC-T

LIDAR



NIRS3

TIR

Science Instruments

MASCOT

by DLR and CNES

MINERVA-II-1

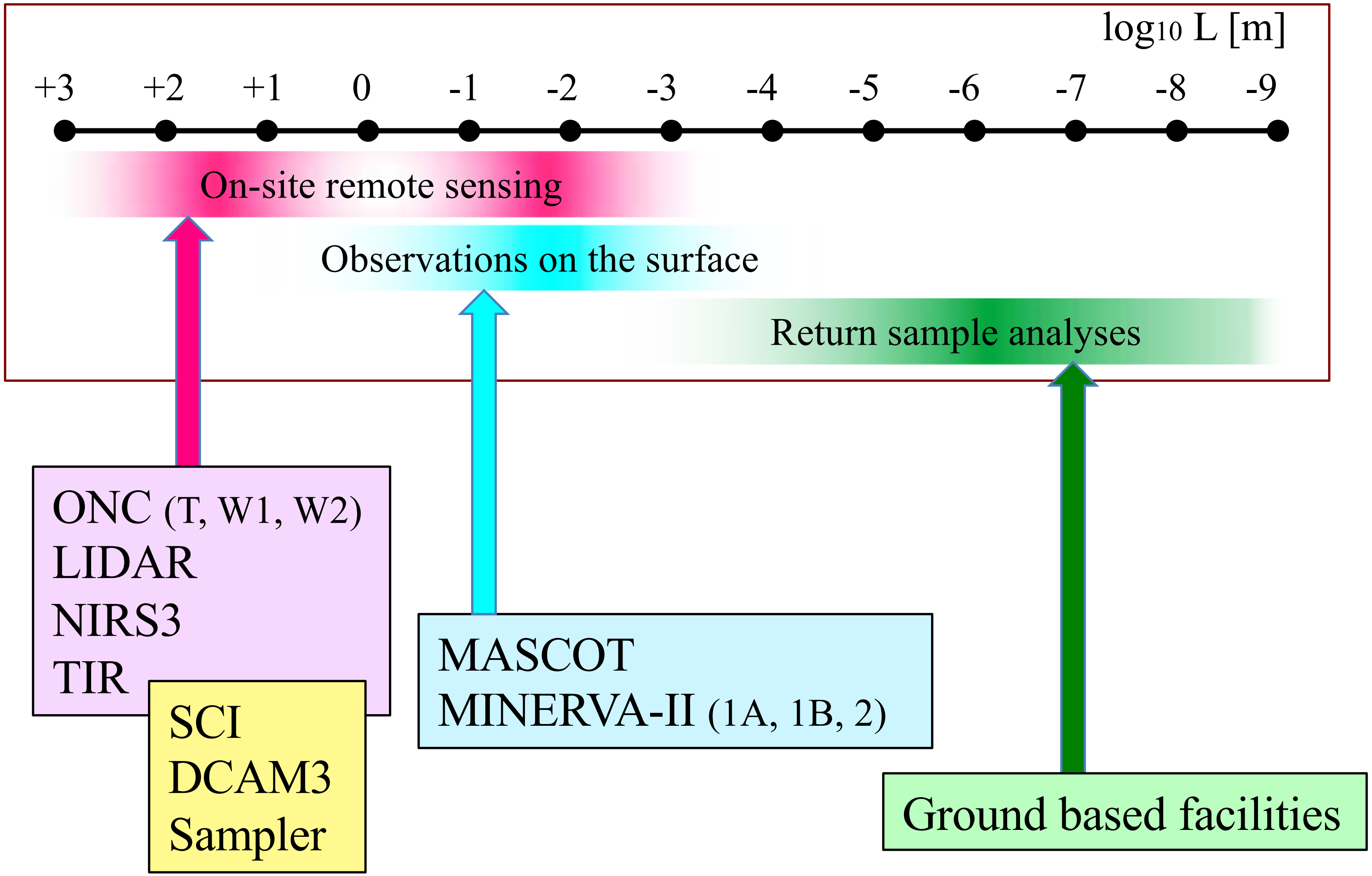
MINERVA-II-2

II-1 : by JAXA MINERVA-II Team
II-2 : by Tohoku Univ. & MINERVA-II consortium

Small Lander and Rovers

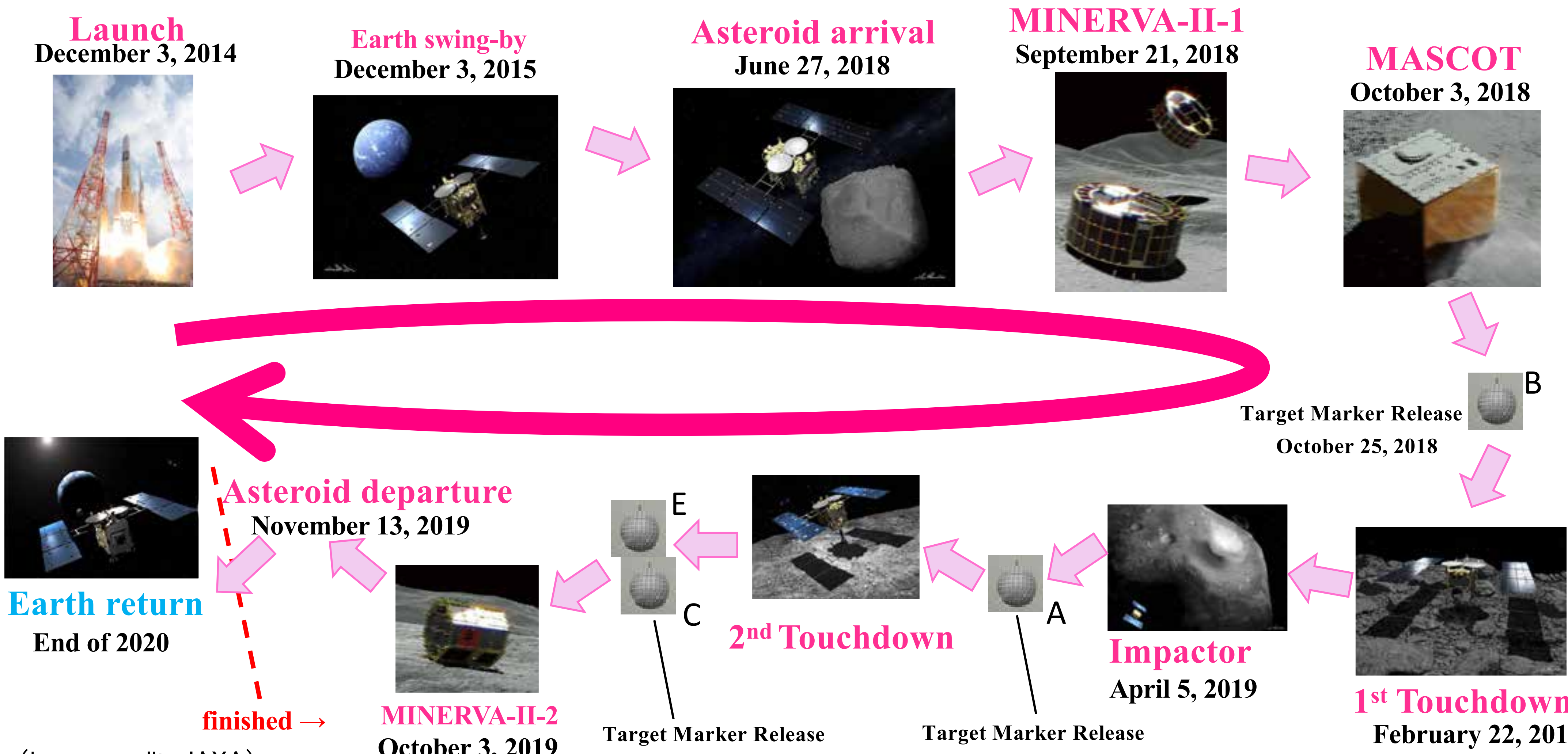
(image credit : JAXA)

Science in Wide Scale Range



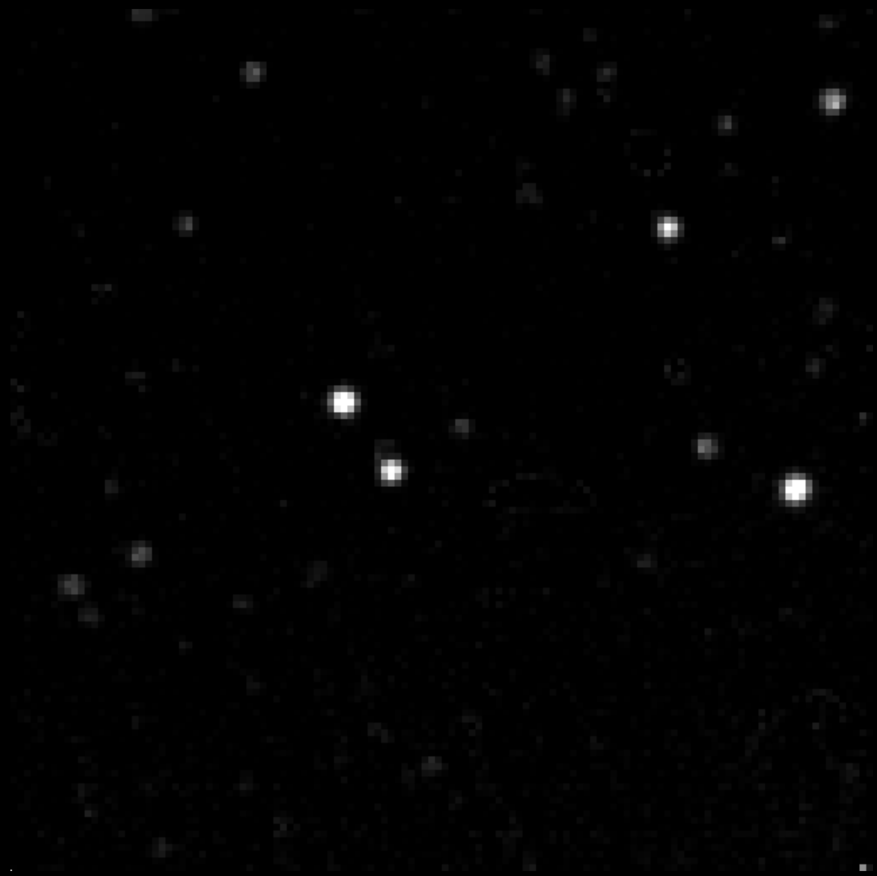
(image credit : JAXA)

Hayabusa2 : Outline of mission flow



(image credit：JAXA)

The first image of Ryugu

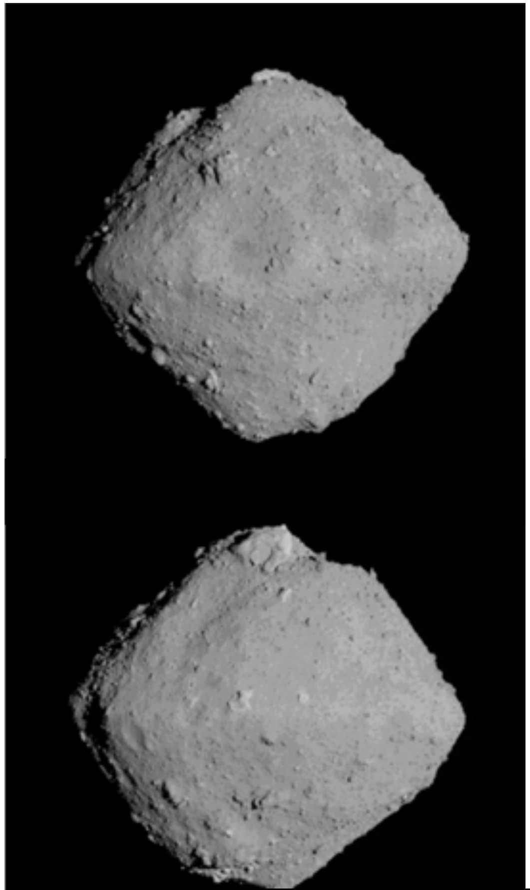


This image was taken by ONC-T on Feb. 26, 2018.
The distance form the spaecraft was about 1.3 million km.

June 27, 2018, Ryugu Arrival !

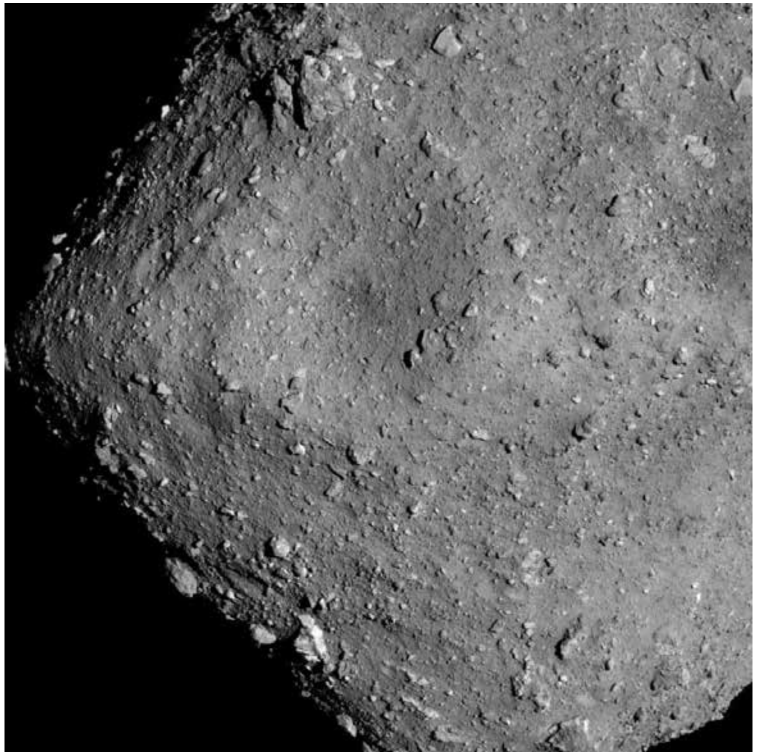
(image credit : JAXA)

Asteroid Ryugu



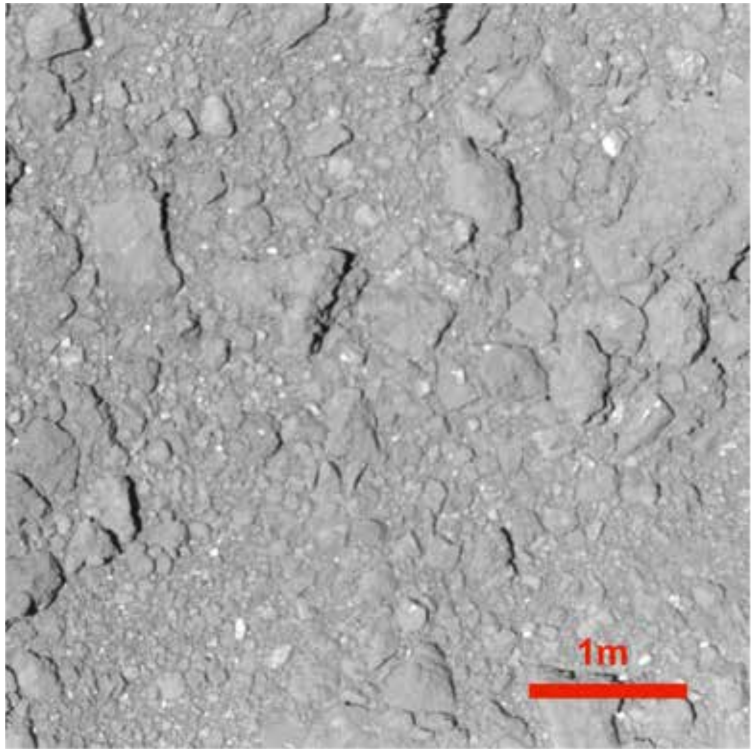
From 20km

June 30, 2018



From 6km

July 20, 2018



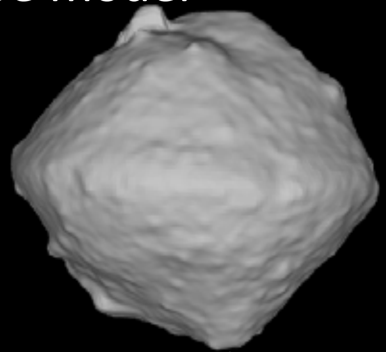
From 42m

October 15, 2018

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

Physical observation of Ryugu

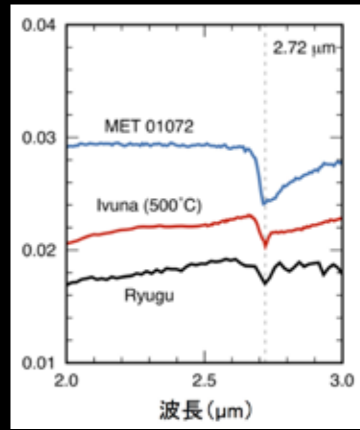
Shape model



(credit: shape model team)

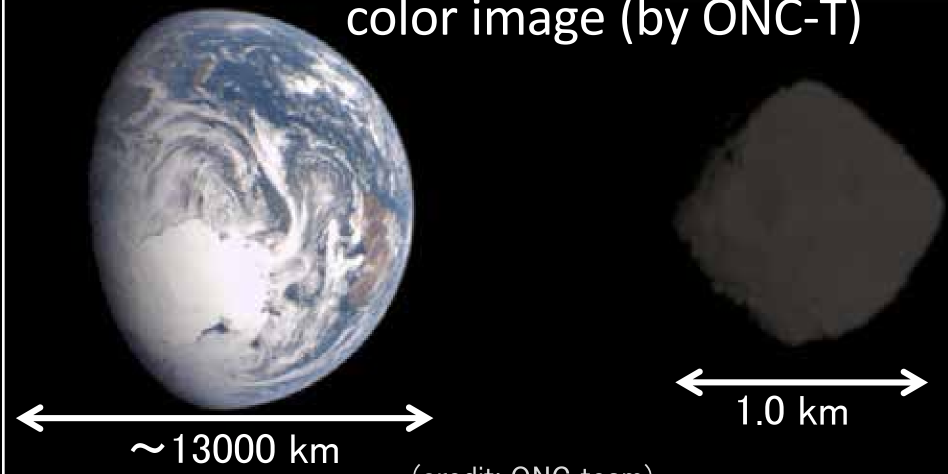
(credit: LIDAR team)

Near infrared spectrum (by NIRS3)



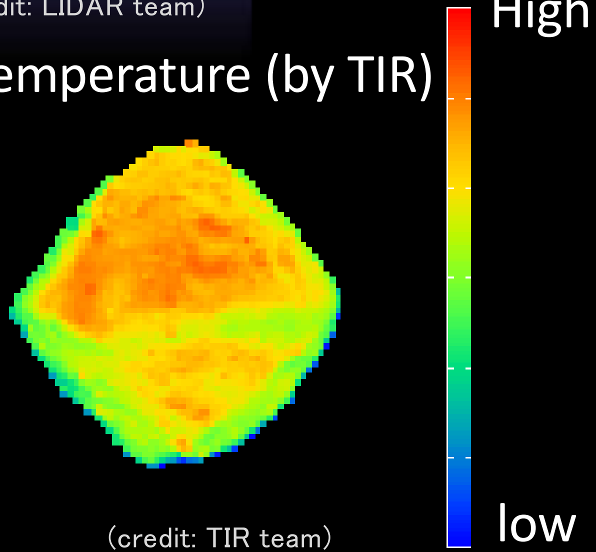
(credit: NIRS3 team)

color image (by ONC-T)



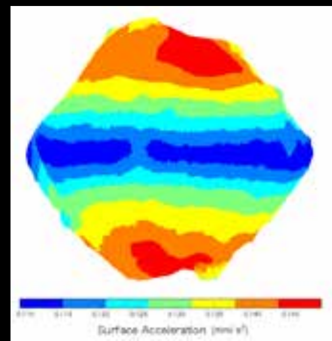
(credit: ONC team)

Temperature (by TIR)



(credit: TIR team)

gravity



(credit: astrodynamics team)

Views on the surface of Ryugu by MINERVA-II-1

September 22, 2018

hopping on the surface
September 22, 2018

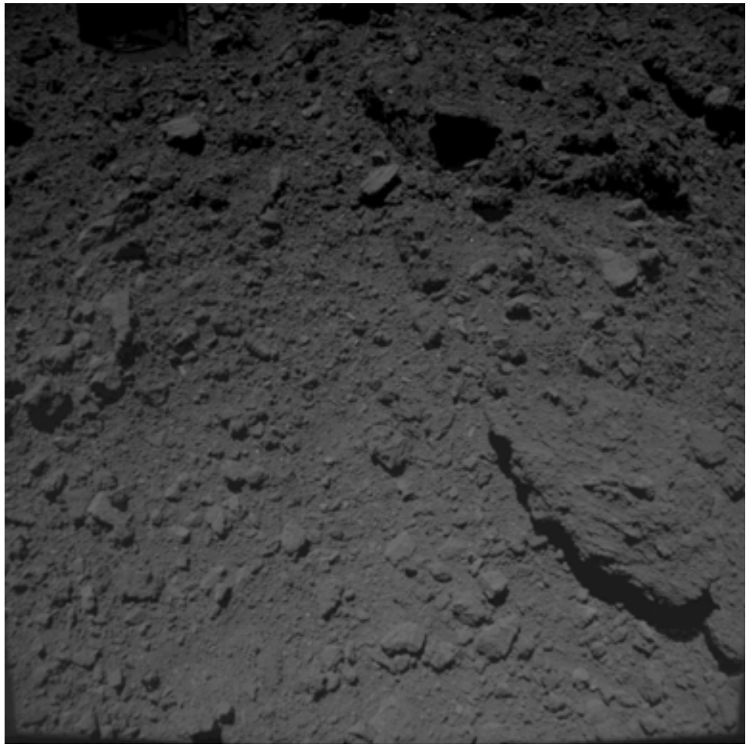
surface view
September 23, 2018

diurnal motion
September 23, 2018

(image credit : JAXA)

Views by MASCOT

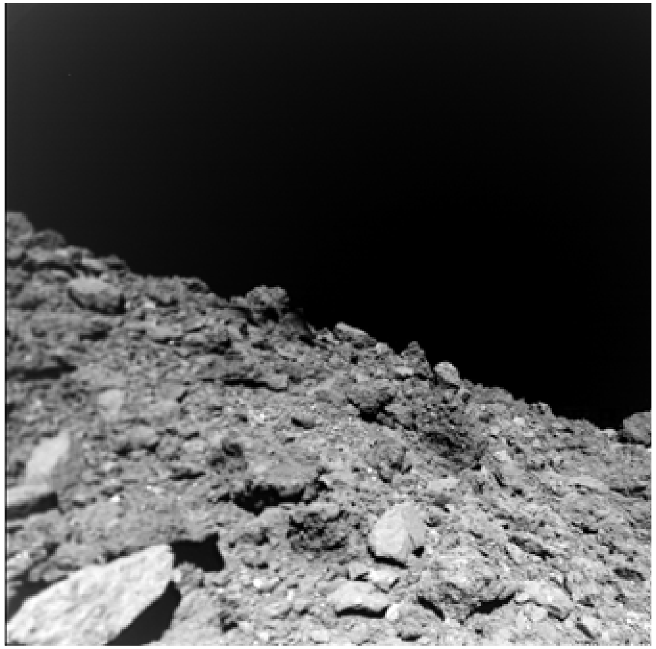
October 3, 2018

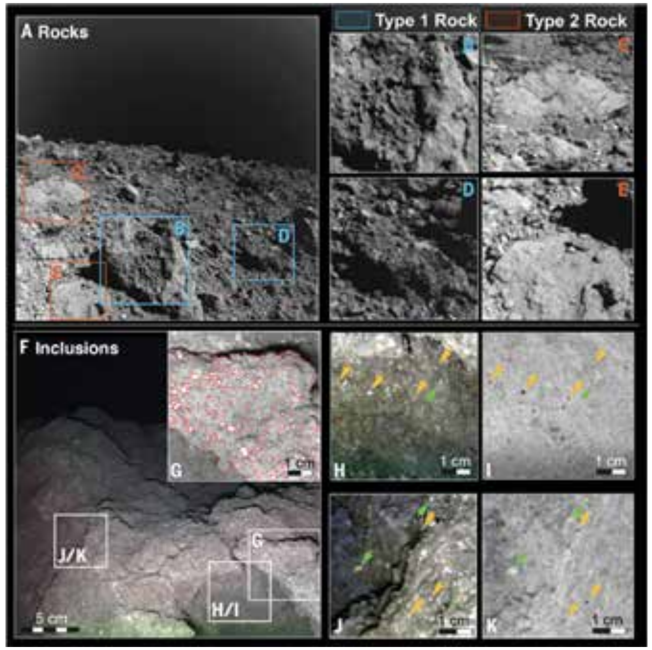


MASCOT Separation

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

Jaumann et al., Science 365, 817–820 (2019)

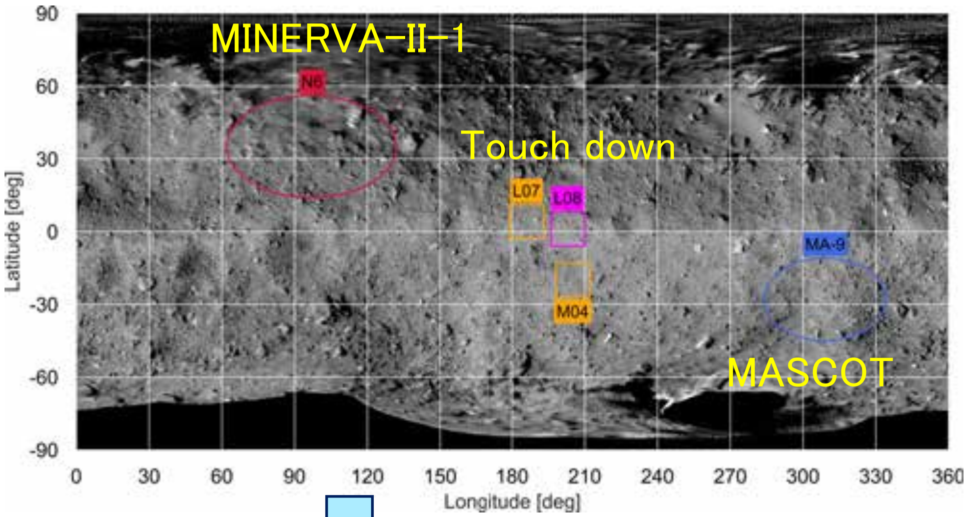


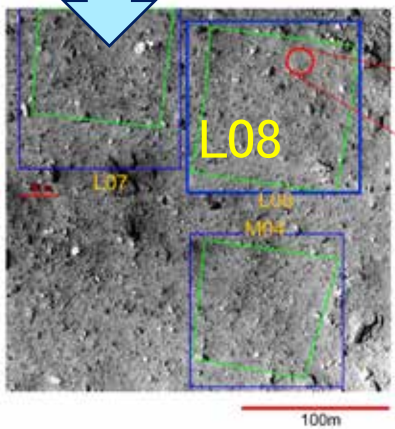


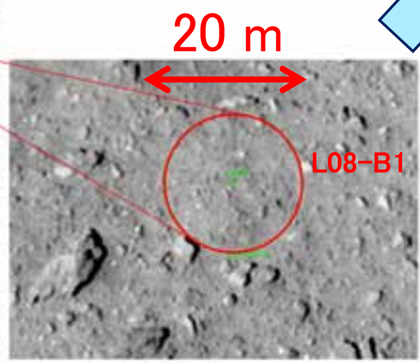
Surface of Ryugu observed by MASCOT

(image credit：MASCOT/DLR/JAXA)

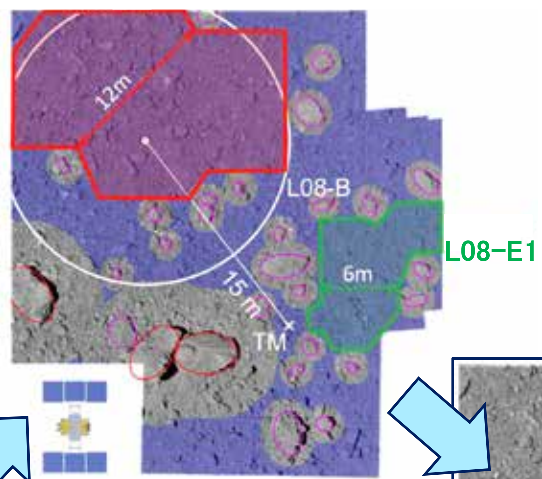
Touchdown site selection





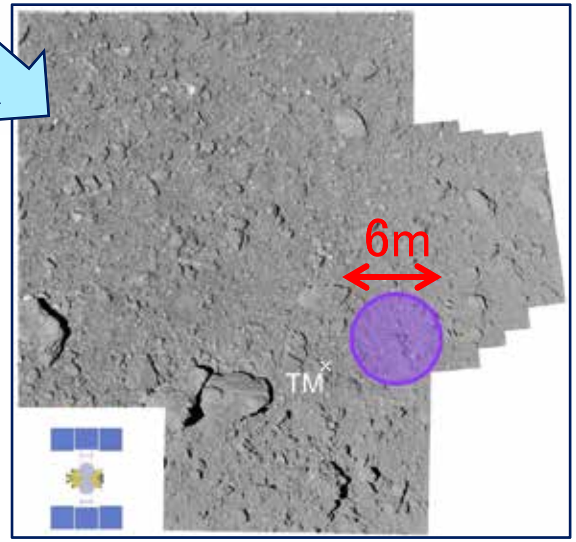


L08-B1 is selected for the possible touchdown site



TM: Target Marker

finally L08-E1 was selected



(image credit: ONC team)

Target maker release

Octover 25, 2018

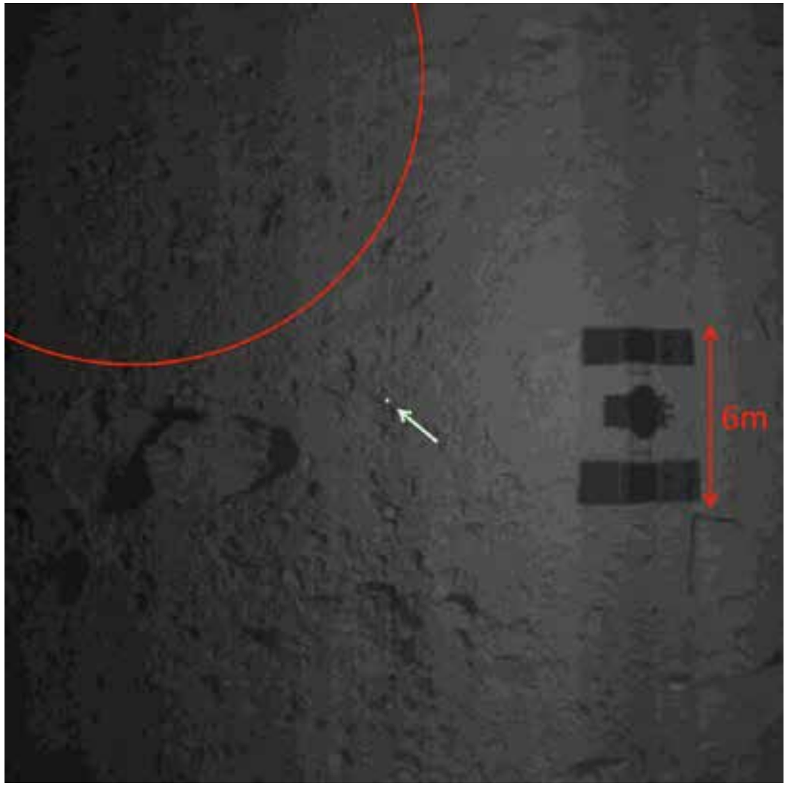


Image taken at the
altitude of 20m

Tracking the target marker after release. The images were captured from October 25, 2018 at 11:38 to 11:48 JST. The altitude is about 12m at the beginning of the movie and 56m at the end.（movie 40x speed）

(Credit:JAXA)

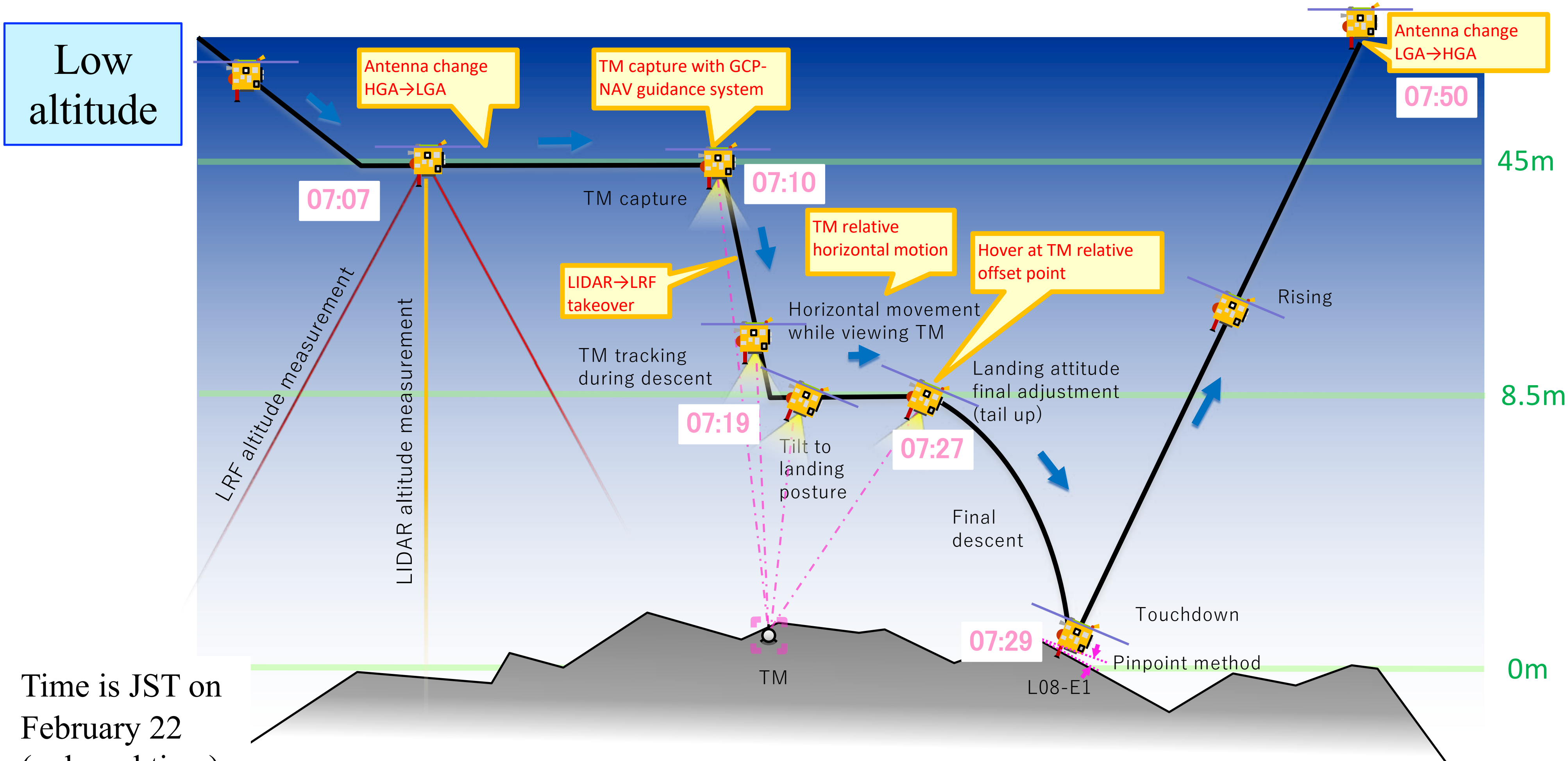
Flying above Ryugu by CAM-H

Octover 25, 2018

Images were taken every 1 second except the beginning and the end (every 5 seconds).
The altitiude change is from 21m to 200m.

(Image credit：JAXA)

The 1st touchdown operation



Time is JST on February 22 (onboard time)

(Image credit：JAXA)

The 1st Touchdown

February 22, 2019

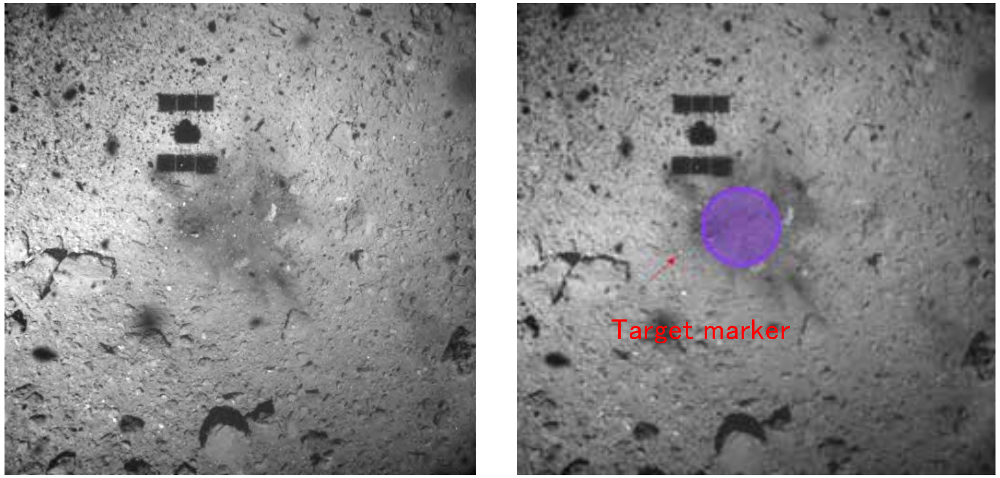


Image taken after the touchdown (by ONC-W1)

- Time of touchdown：Feb. 22, 2019 07:29:10
  （JST, onboard time）
- Accuracy of navigation：1m

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

Images taken by the small monitor camera (CAM-H) before and after the touchdown。The images were taken from 59 sec before the touchdown for 5 min and 40sec. (movie: X5)

（image credit：JAXA）

The 1st Touchdown

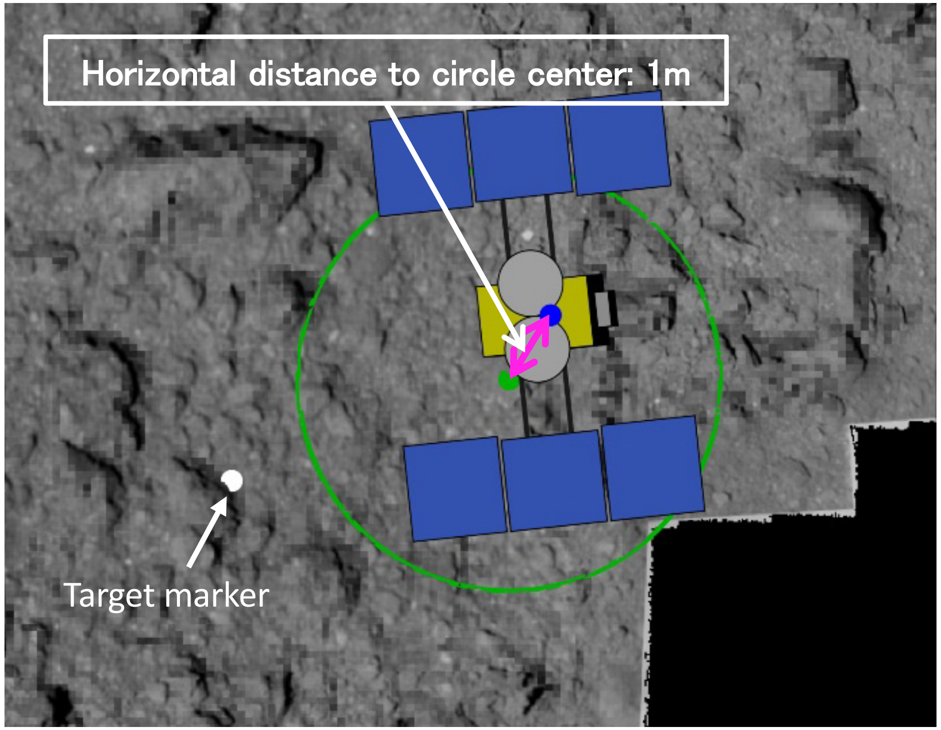
by ONC-W1

Movie of images taken with the ONC-W1 at the time of the first touchdown. (Movie)
（©Morota et al., 2020）

The 1st Touchdown : Landing Accuracy

1m precision landing has been achieved!

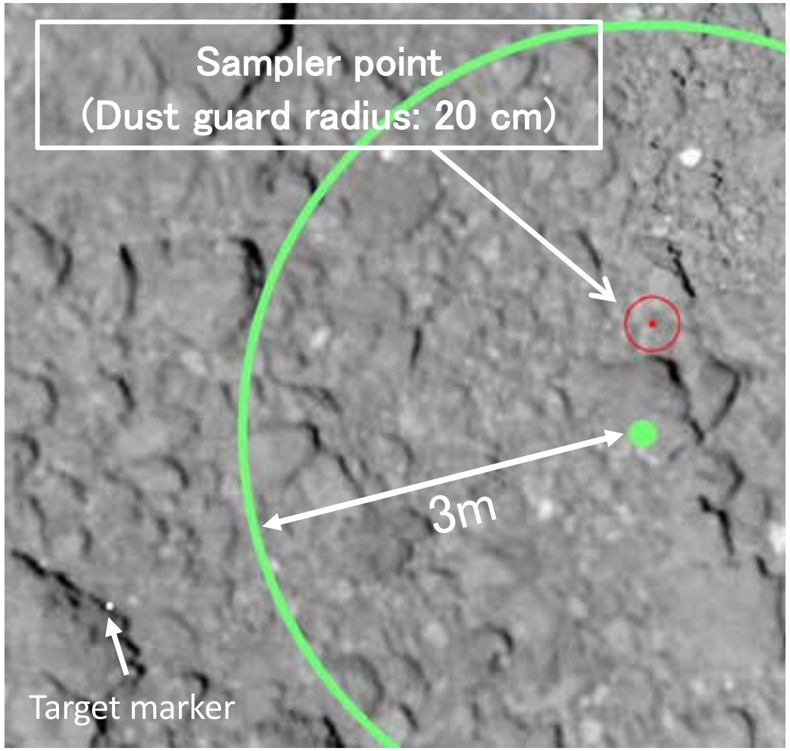
Touchdown point



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).

(image credit : JAXA)

Sampling point

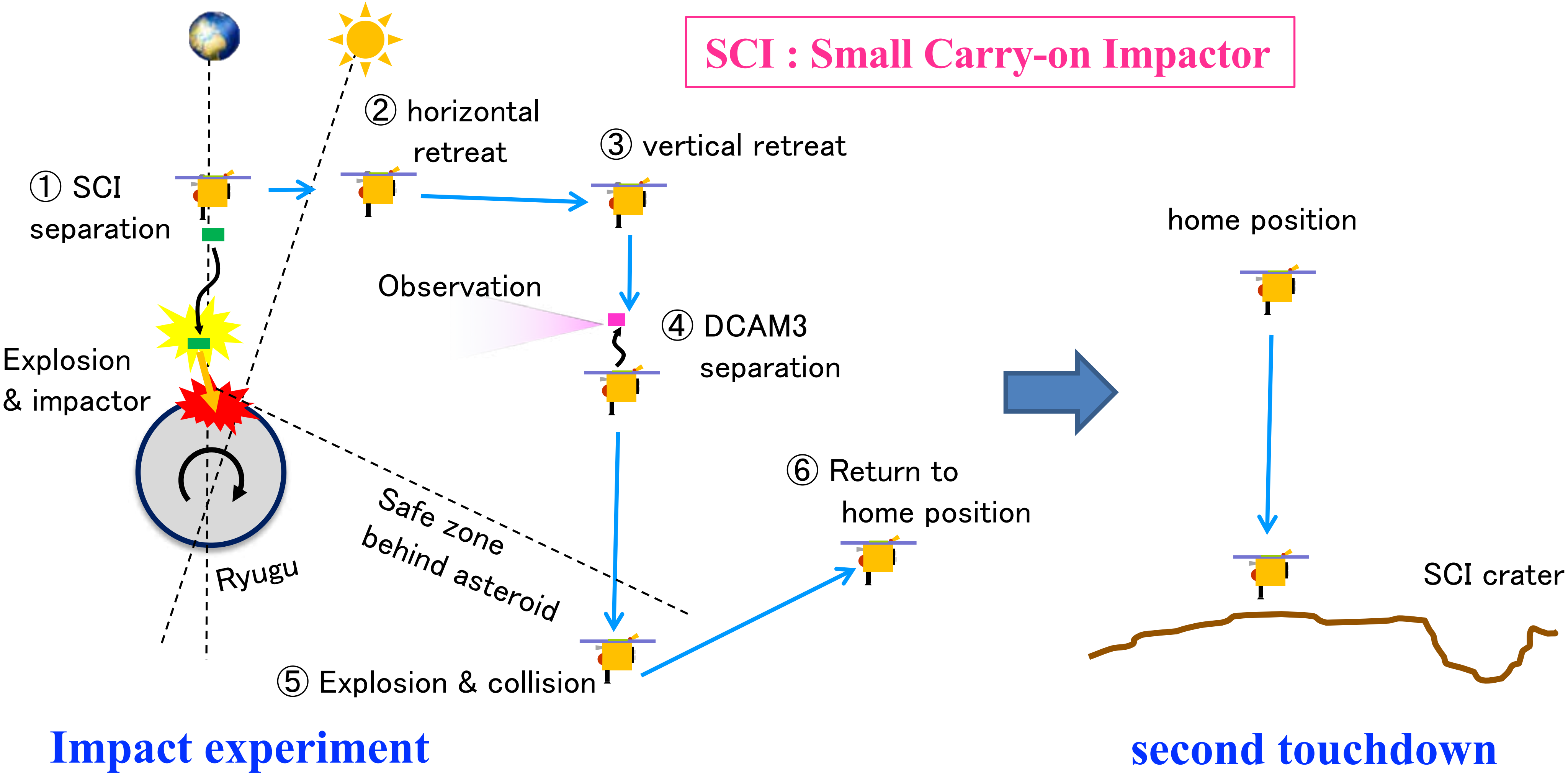


Red circle is where the sampler horn is thought to have touched the surface. Green circle is the planned touchdown site. Background is a real image of Ryugu.

February 22, 2019, Scucess of the 1st touchdown!

(image credit : JAXA)

Impact experiment and second touchdown



（image credit：JAXA）

SCI separation and ejecta

April 5, 2019

SCI just after separation

by ONC-W1

(image credit : ONC team)

by TIR

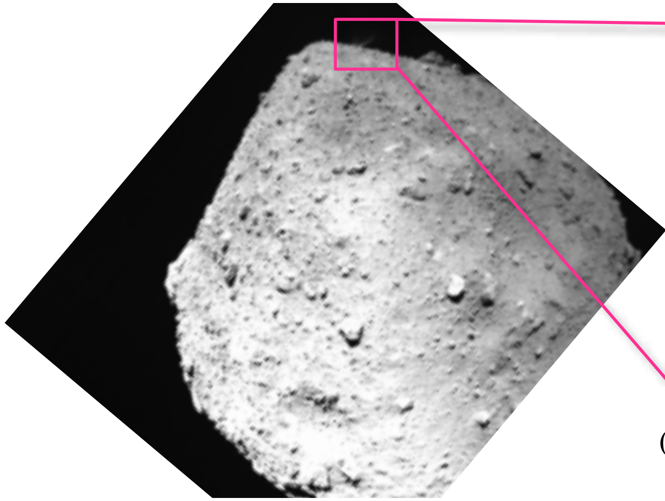
(image credit : TIR team)

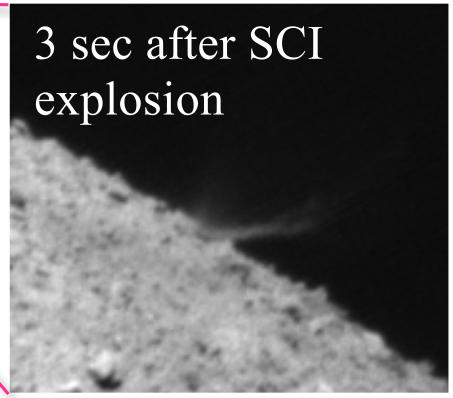
Ejecta by SCI impact

DCAM3 : analogue system

(image credit : DCAM3 analogue team)

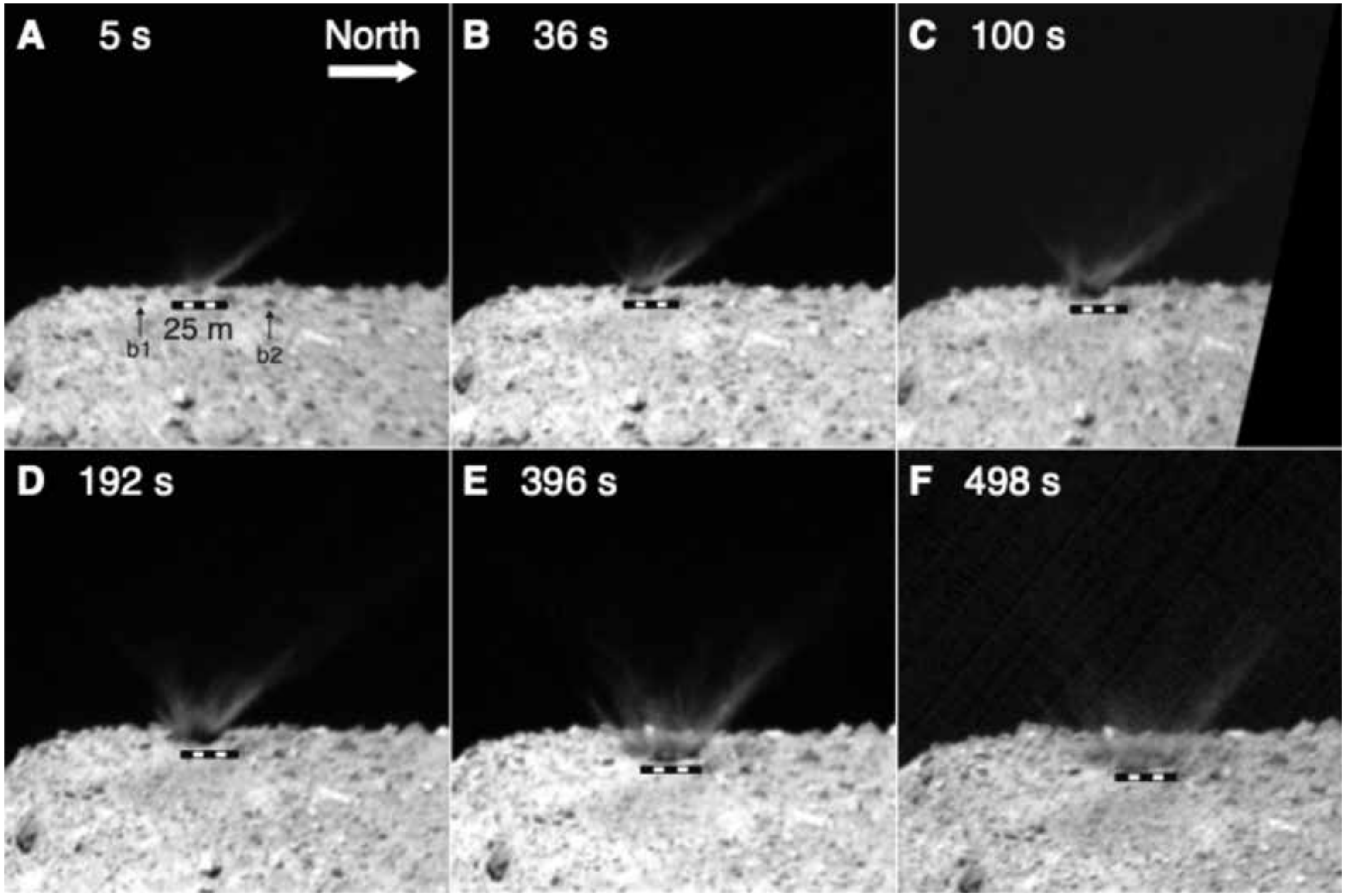
DCAM3 : digital system





(image credit : DCAM3 digital team)

Ejecta curtain



Arakawa et al., 2020

Artificial crater

Observed on April 25, 2019

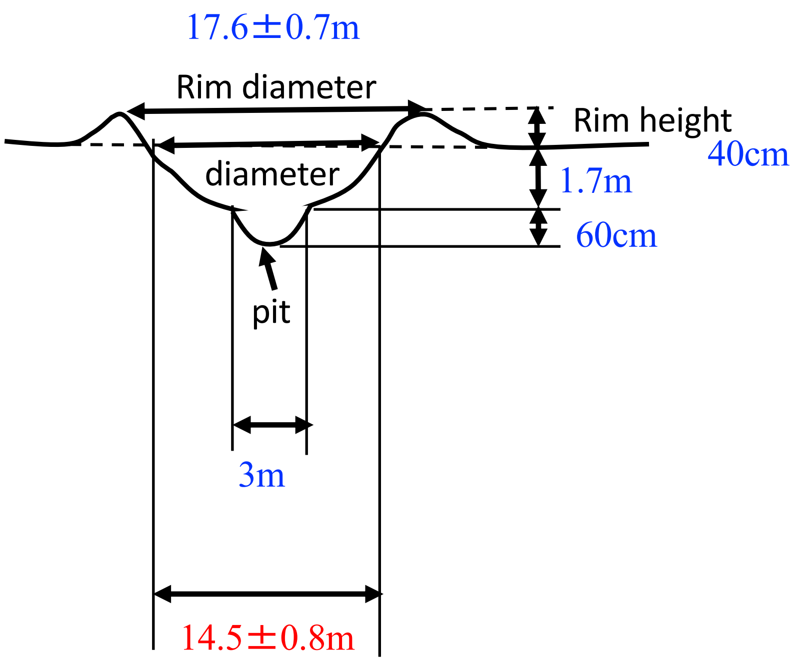
before SCI impact 2019/03/22

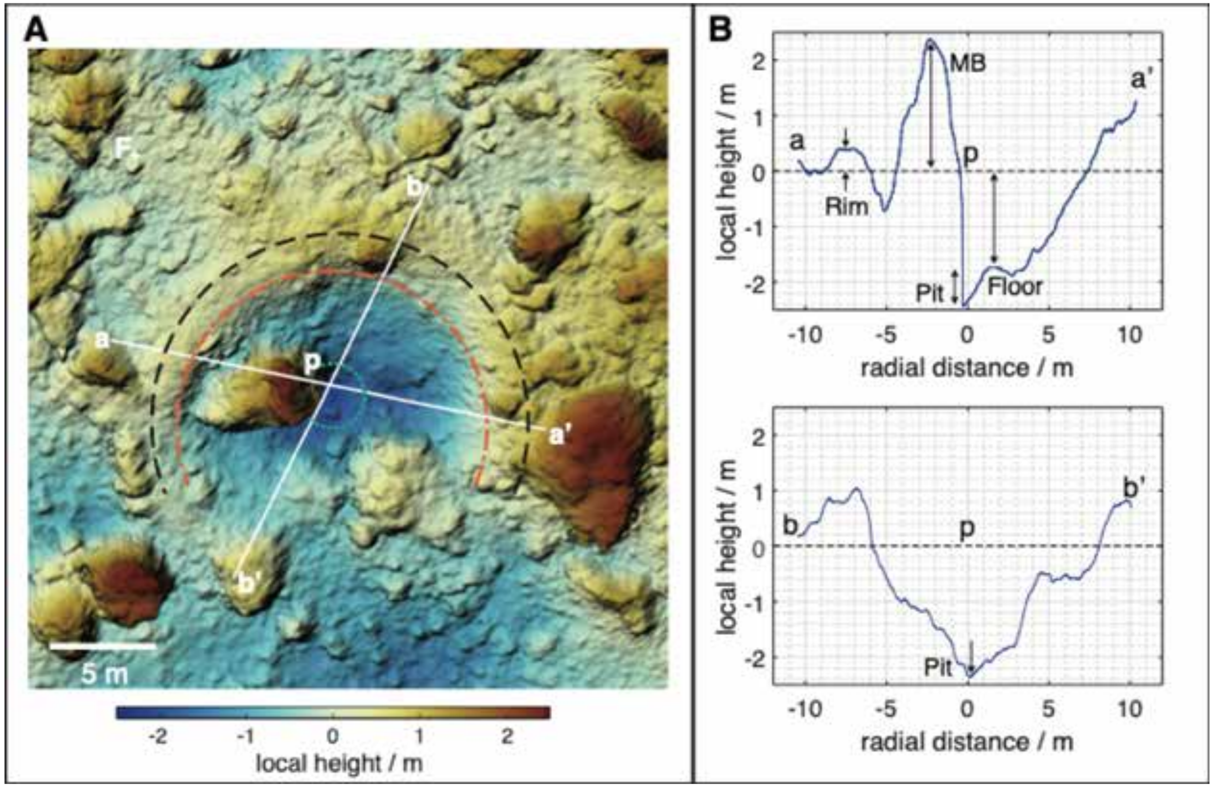
after SCI impact 2019/04/25

comparison before and after

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

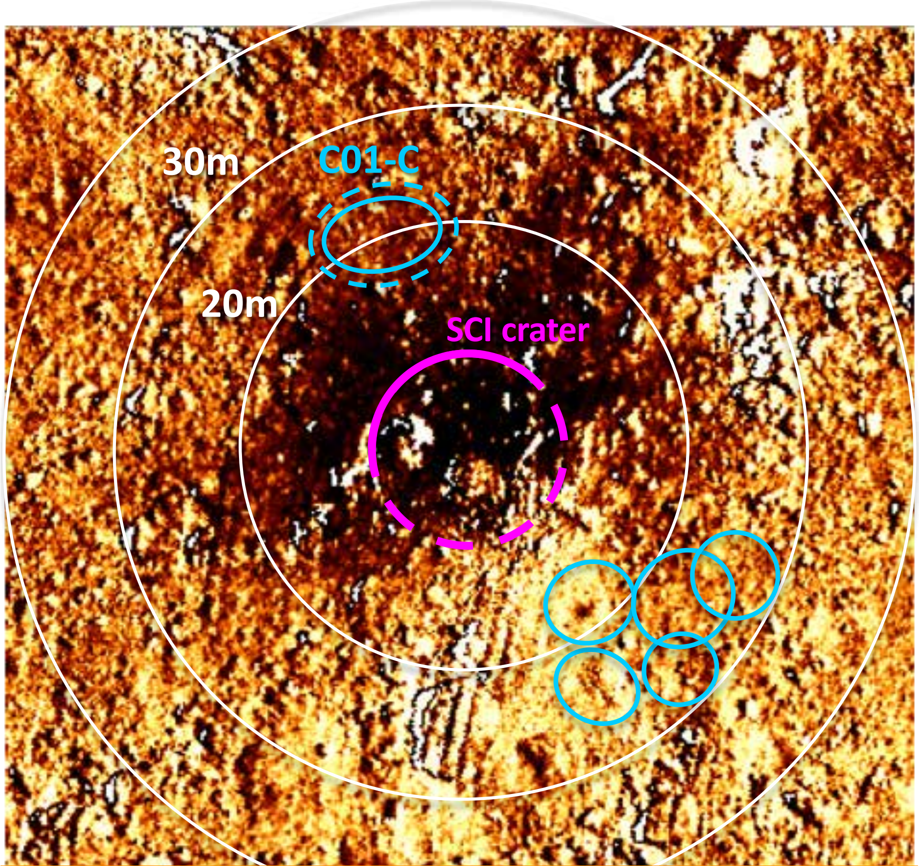
SCI crater shape





Arakawa et al., 2020

Ejecta from the SCI crater



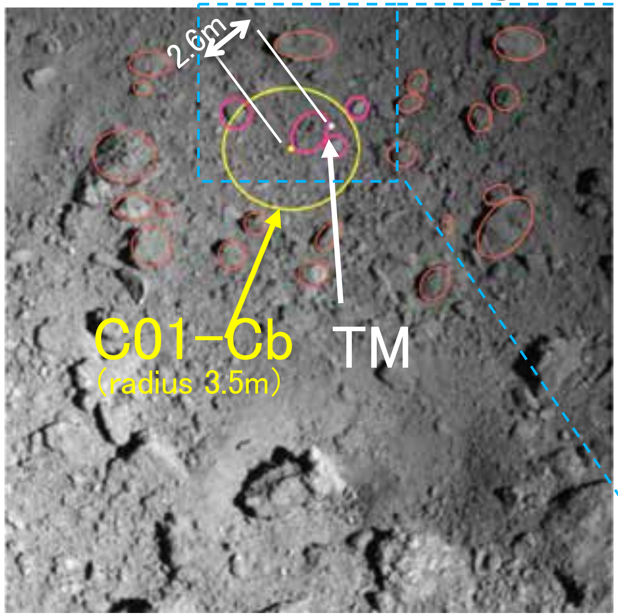
Change in reflectance before and after SCI impact（CRA1 → CRA2）. Contrast emphasized. Black areas darkened after collision.

- Ejecta from the SCI crater (darker colors than the surroudings) is distributed all over the PPTD candidate site, C01-C.
- The average thickness of the ejecta in C01-C is estimated at about 1cm, based on the spatial distribution of the darkening.
- The C01-C ejecta is thought to be a mix of excavated material from depths of 0m to about 1m. ※ Layers of several 10s cm or more are predicted from space weathering, solar heating and cosmic rays.

Terrain created by adjusting lighting conditions in the ONC image. (JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)

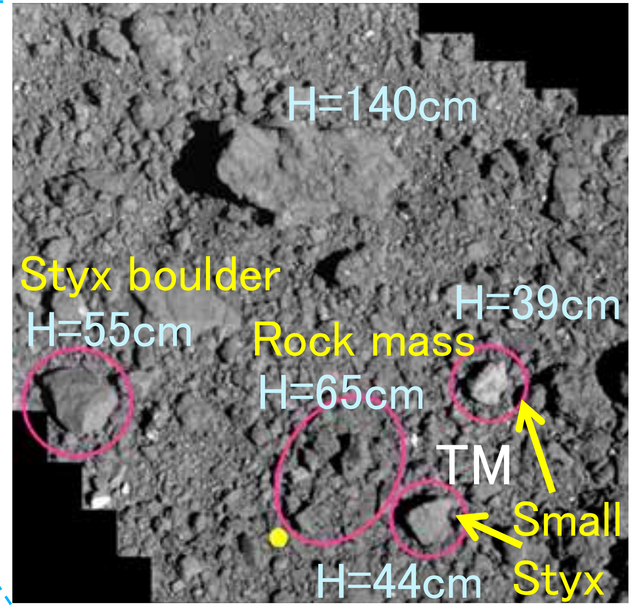
The site of the 2nd touchdown : C01-Cb

PPTD-TM1 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.)

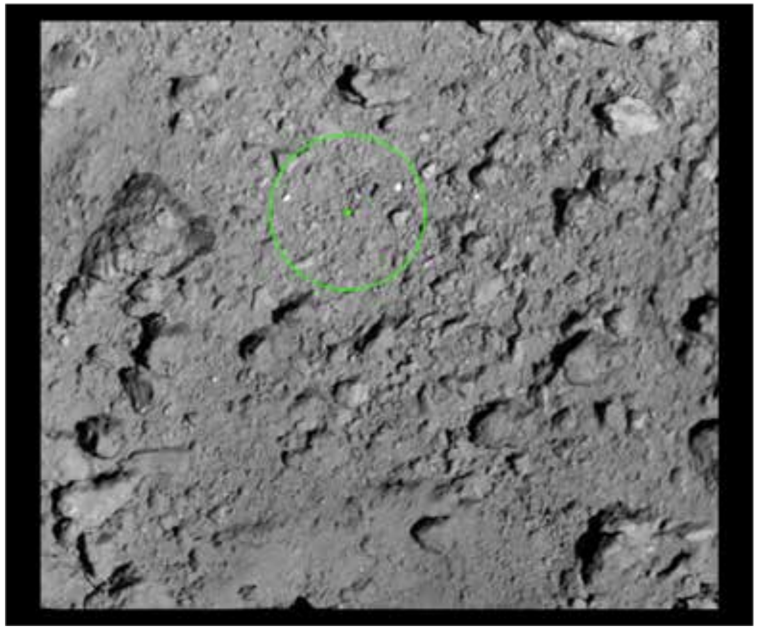
PPTD-TM1B image



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）



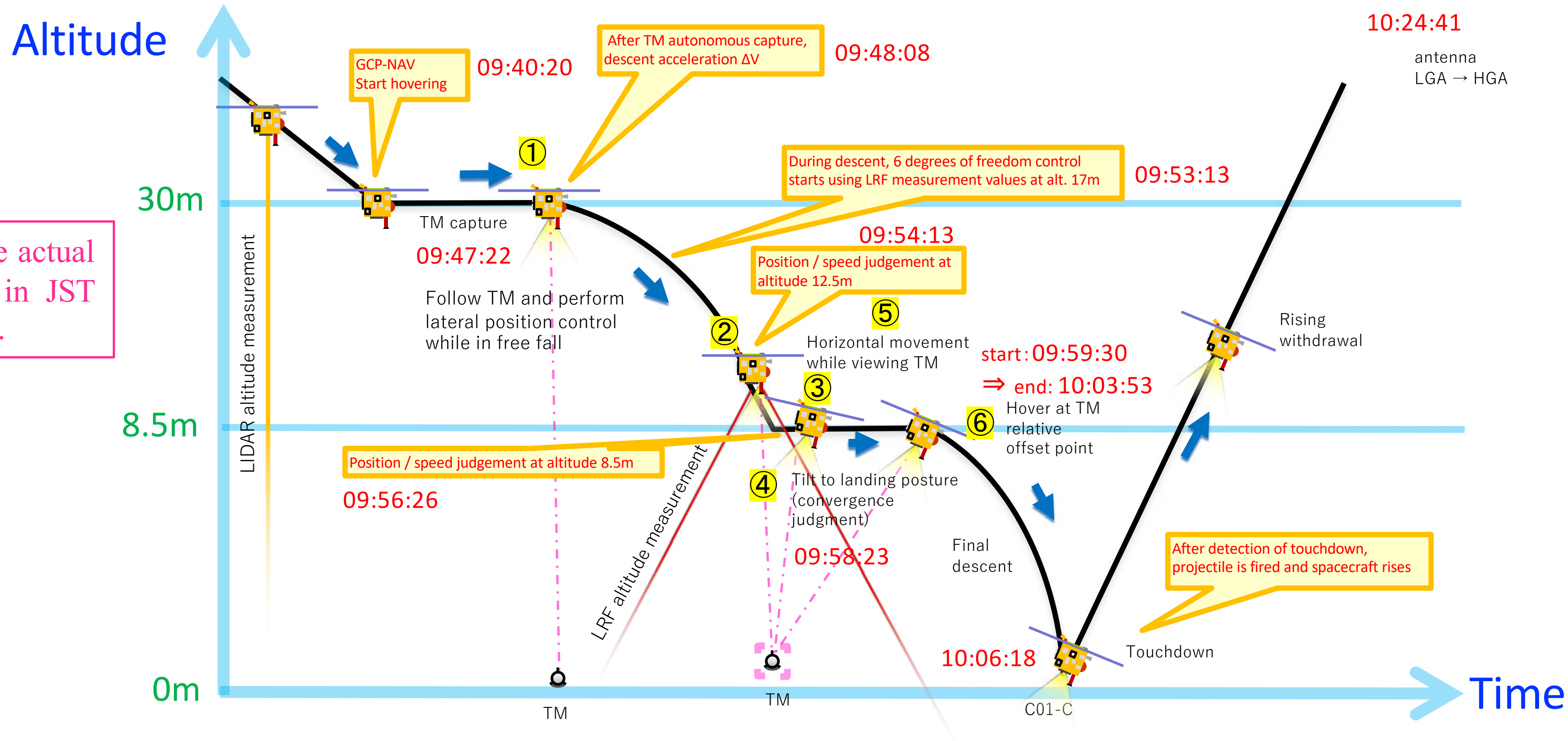
DEM（Digital Elevation Map）near the touchdown candidate point

（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)

The 2nd touchdown operation

Operation sequence (low altitude)

Times shown are actual on-board times in JST on July 11, 2019.



※①～⑥ checkpoints for autonomous judgements as to whether Hayabusa2 continues to the next sequence.

(credit: JAXA)

The 2nd touchdown

July 11, 2019

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

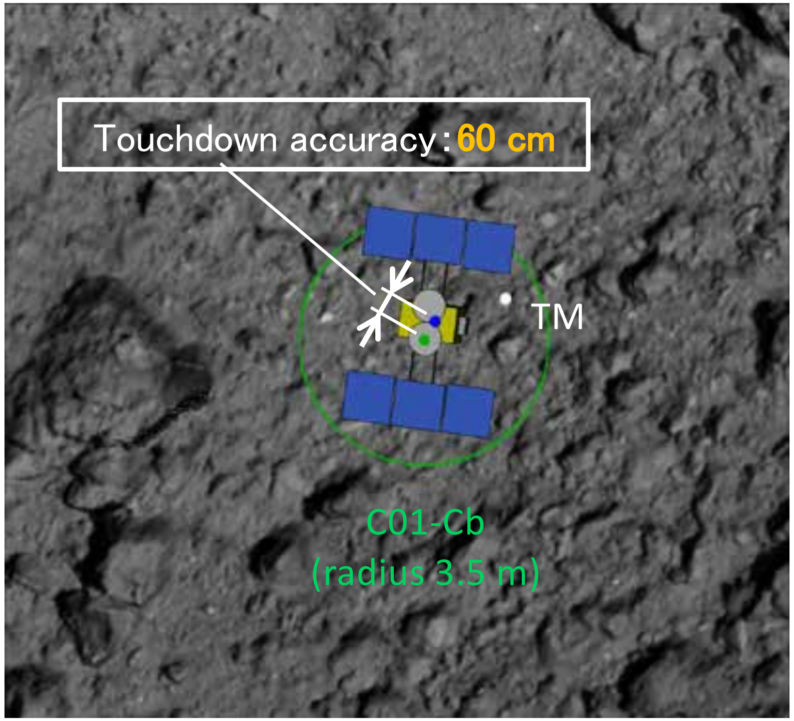
Capture time:
2019/7/11
Start 10:03:54 (altitude 8.5m)
Finish 10:11:44 (altitude 150m)
※image interval between 0.5s~5s

(credit : JAXA)

The 2nd touchdown accuracy

60 cm precision landing has been achieved!

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)

July 11, 2019, Scucess of the 2^{nd} touchdown!

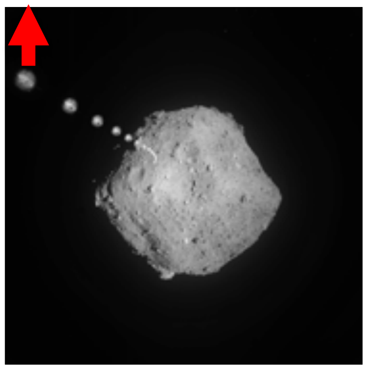
(image credit : JAXA)

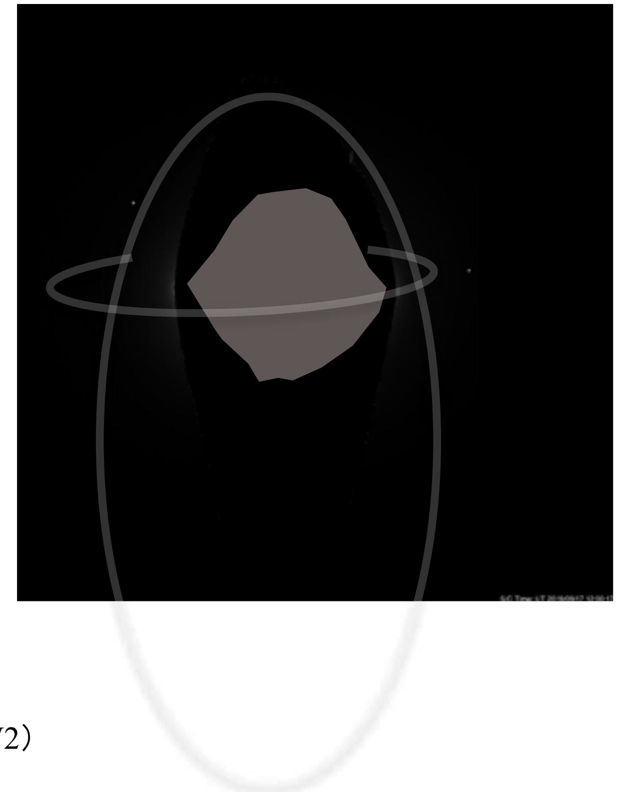
Target Markers/Rover : Orbiting around Ryugu

- Objective: Gravity science
- Two TMs were inserted to r=1.5km equatorial and polar orbits on Sep 16, 2019.
- MINERVA-II-2 rover was inserted to r=1.5km equatorial orbit on Oct 2, 2019.
- Three objects were successfully tracked by ONC-T for several days!

TM-E separation（ONC-W1）
（2019/9/16 16:17UTC）

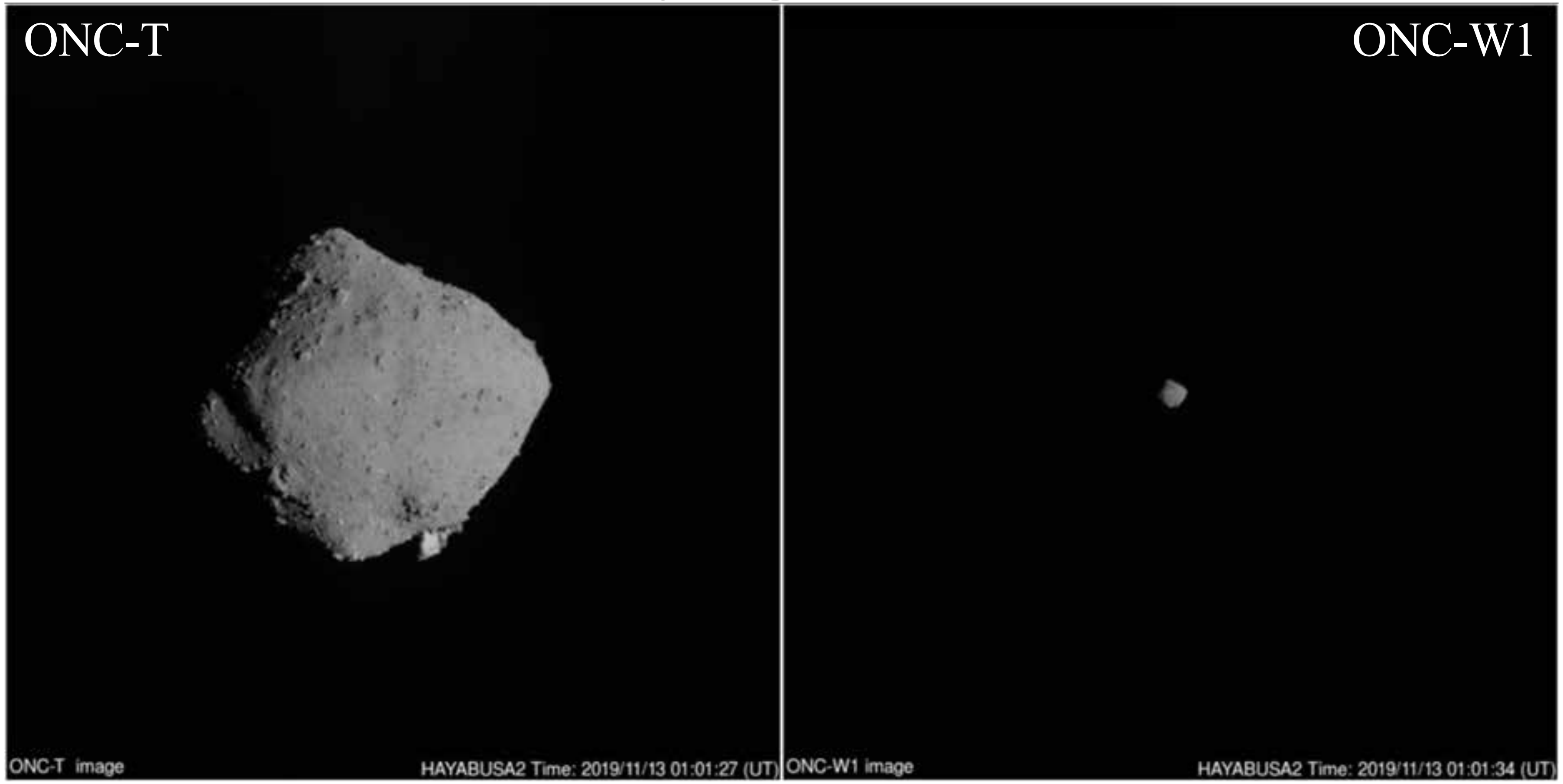
TM-C separation（ONC-W1）
（2019/9/16 16:24UTC）





MINERVA-II-2 separation（ONC-W2）
（2019/10/2 15:57UTC）

Farewell, Ryugu! Nov. 13-19, 2019

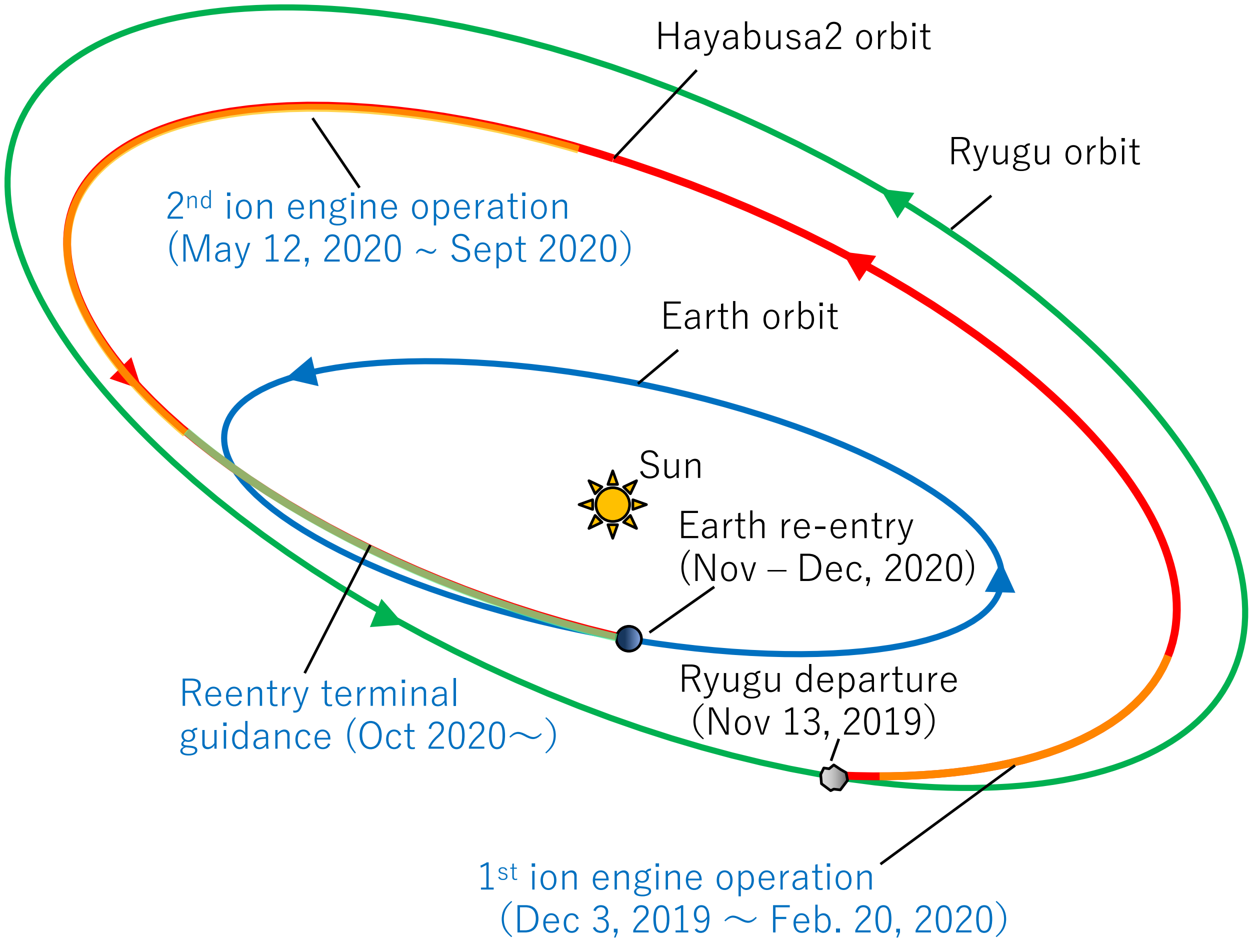


Animation created from a continuous set of navigation images captured during the departure from Ryugu from November 13, 2019 until the disappearance of Ryugu due to attitude control on November 19, 2019. (Image credit※: JAXA, Chiba Institute of Technology, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, University of Aizu, AIST).

November 13, 2019, Ryugu Depature

(image credit : JAXA)

Hayabusa2 Return Phase Trajectory



（image credit：JAXA）

Hayabusa2 capsule return

- Hayabusa2 plans to return to Earth at the end of 2020 and separate the capsule.
- As with the recovery from the first Hayabusa in 2010, JAXA is currently working with the Australian Government to facilitate the recovery of the Hayabusa2 re-entry capsule in 2020 at the Woomera Prohibited Area (WPA).

Image of the recovery candidate site (photographed in December 2018)

(Image credit: JAXA)

International Cooperation on Hayabusa2

Germany — France

DLR — CNES

Japan

Hayabusa2

JAXA

OSIRIS-REx

Australia

ASA
DOD
DSTG

USA

NASA

Hayabusa2 Joint Science Team (HJST)

Group photograph of the Hayabusa2 Joint Science Team (HJST) meeting held at LPSC (March 21, 2019). (Photo credit: Hayabusa2 Project.)

（image credit : JAXA）

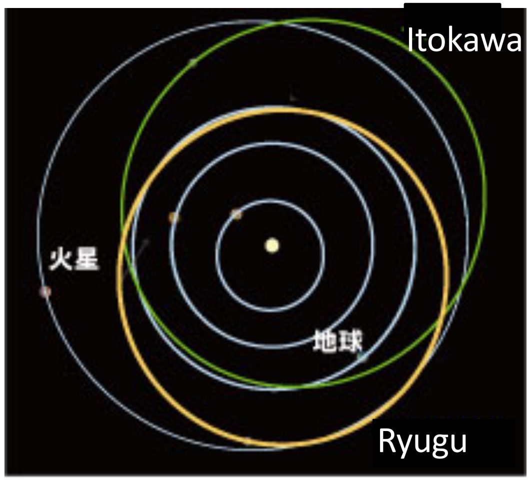
Data of Ryugu by initial observations

Name : (162173) Ryugu
Provisional designation : 1999 JU3

Size : equatorial radius ~500m、polar radius ~440m
Spin period : ~7hour 38min
Orientation of spin axis : almost perpendicular to the ecliptic plane (obliquity ~8deg)
Orbital period : ~1.3years

Mass : 4.50×10^{11}kg
Volume : $0.377 km^3$
Density : $1.19 g/cm^3$ → Porosity is more than 50% → rubble pile object
Shape : spinning top → rotation was fast in the past? 3.5hours?
Albedo : 4.5
Material : hydrated mineral, heating and collisions?

Orbit of Ryugu



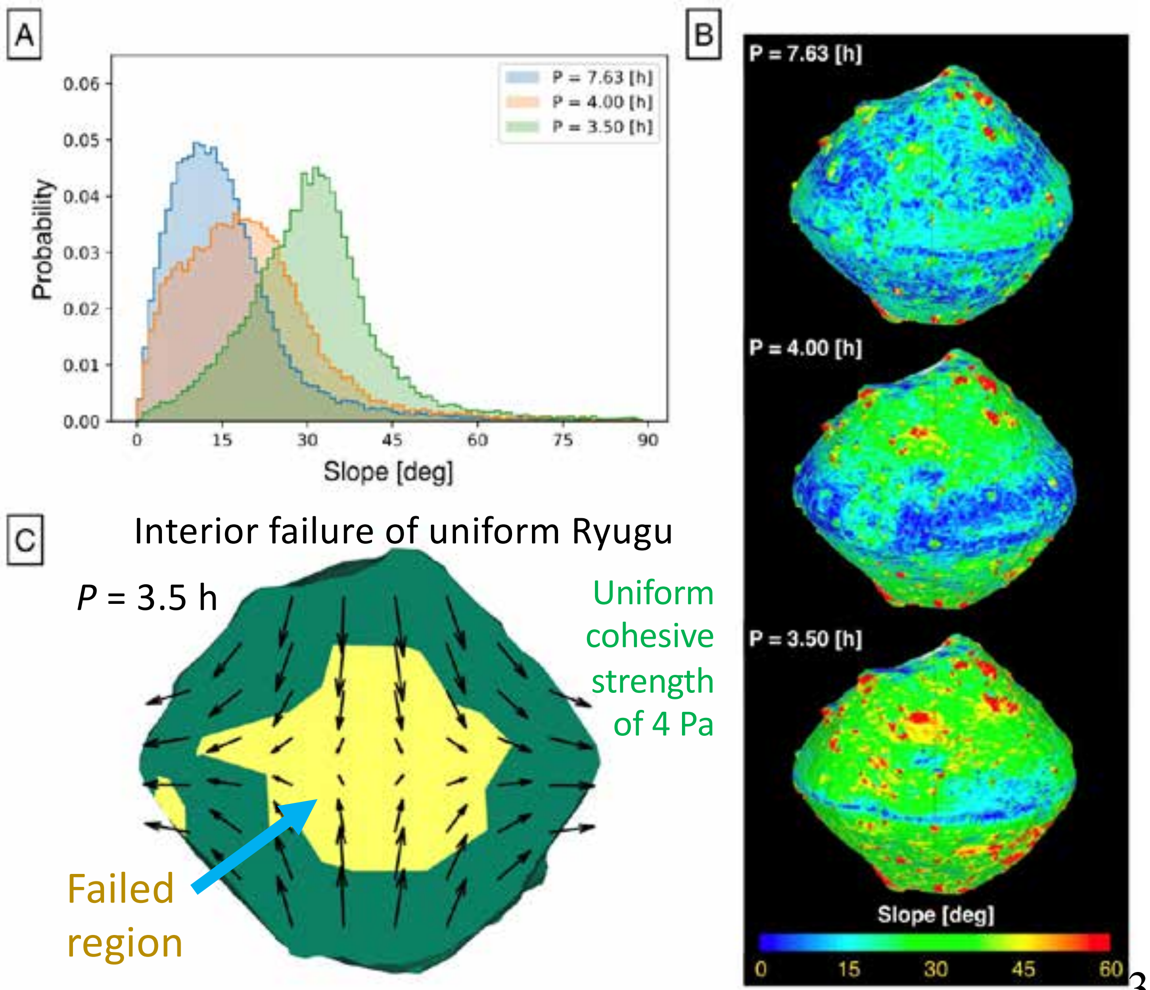
(Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST)

Shape

Ryugu's top shape was formed by past rapid spin

Watanabe+ 2019 *Science* **364**

- Using the derived bulk ρ (= 1.2 g/cm^3) and shape model, we calculated the surface slope distributions [A] and maps [B] at different rotation periods *P*, assuming a uniform ρ distribution.
- **At *P* = 3.5 h**, the surface slopes (centered at 31° [A]) become close to typical friction angle of granular materials: ~35° , and **the variation in surface slopes becomes minimum** [B]. This shows that the top shape was formed at this rotation period.
- Plastic FEM simulation [C]: At *P* = 3.5 h, **interior failure is induced** if the cohesive strength is uniform and low in the body. **The failed region** spreads over the interior, driving outward, radial deformation parallel to the equatorial plane and inward, vertical deformation around the spin axis.



NIRS3

Near-infrared spectroscopy of Ryugu

Kitazato+ 2019 *Science* **364**, 272.

Features of the spectrum of Ryugu :

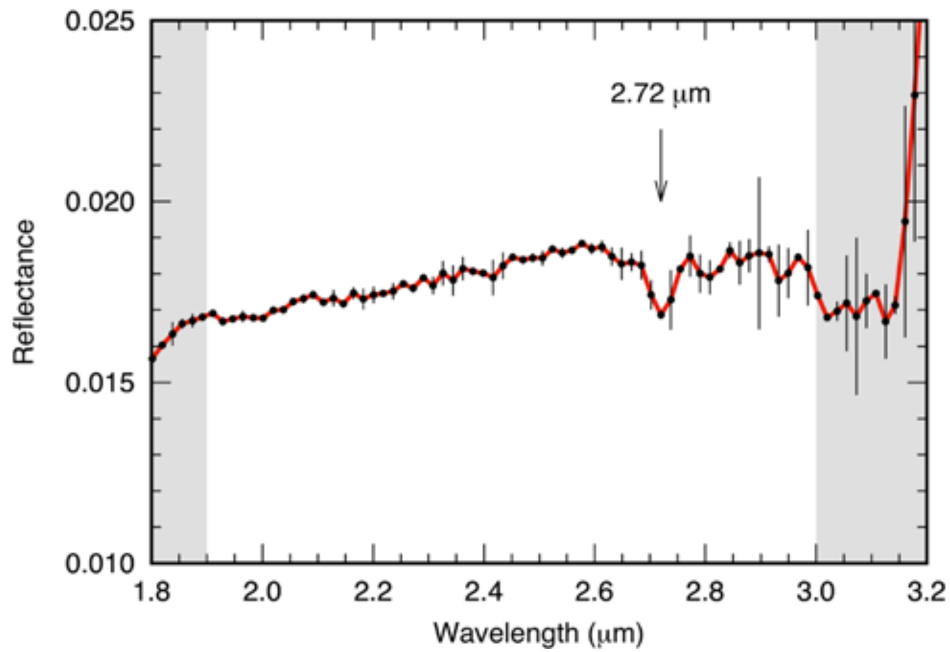
(1) very low reflectivity (about 2%)

(2) gentle increase gradient of spectrum

(3) weak absorption at 2.72μm

⇩

- Water exits as hydrated minerals on the surface of Ryugu
- The spectrum of Ryugu is similar to that of heated or shocked carbonaceous chondrite
- The composition of the surface material of Ryugu is homogeneous and this represents the characteristics of the chemical reaction of water and minerals



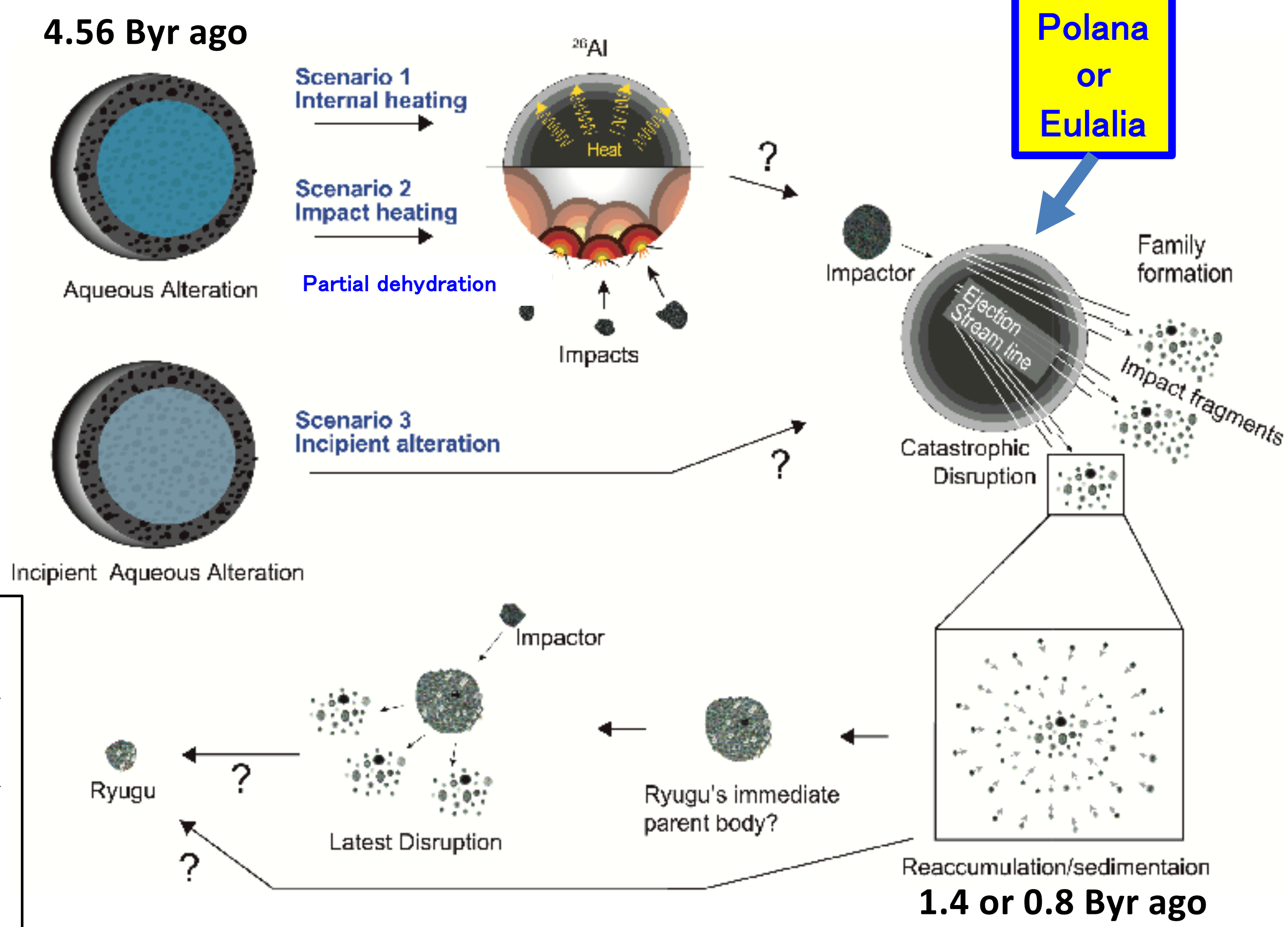
Near-infrared spectrum of Ryugu observed by NIRS3. In the gray region, the uncertainty of the data is lager than the error bar.

ONC

The evolution of Ryugu and its parent body

Sugita+ 2019 *Science* **364**, 272.

- Ryugu is likely produced from either Polana or Eulalia via collision-induced breakup.
- The parent body likely experienced water-rock reaction to form hydrated minerals.
- It subsequently lost a large fraction of hydrated minerals via thermal dehydration due to radiogenic heat.

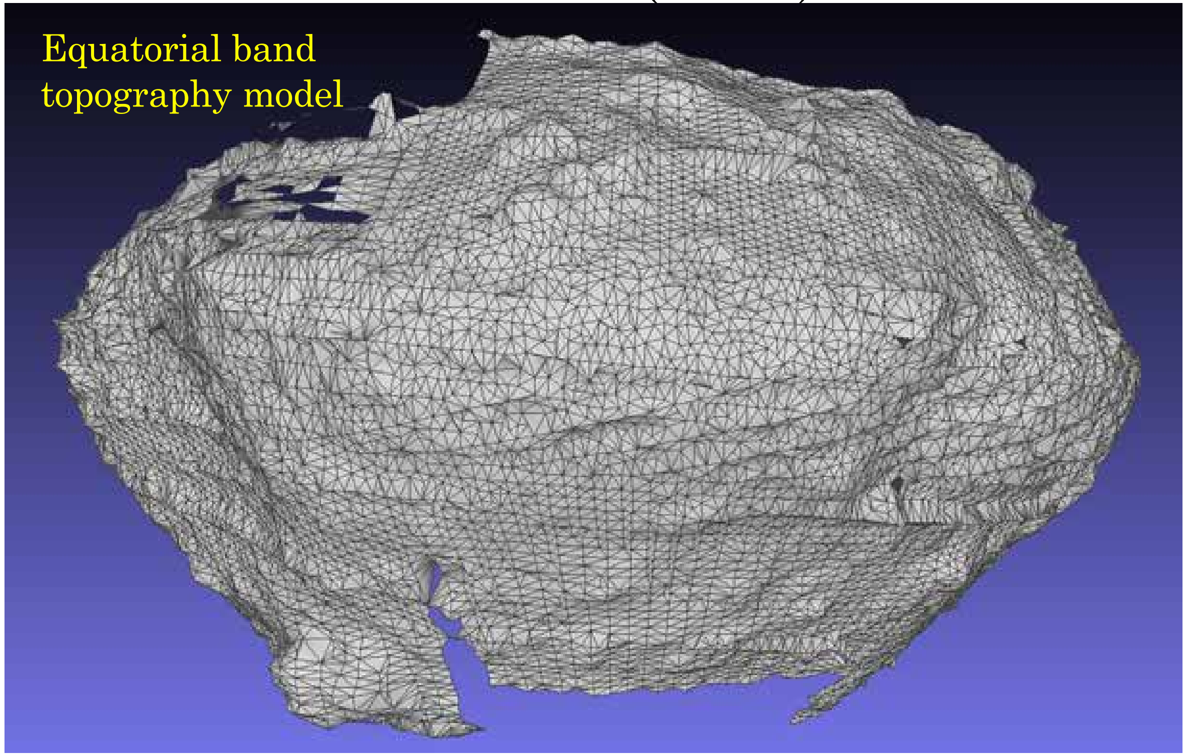


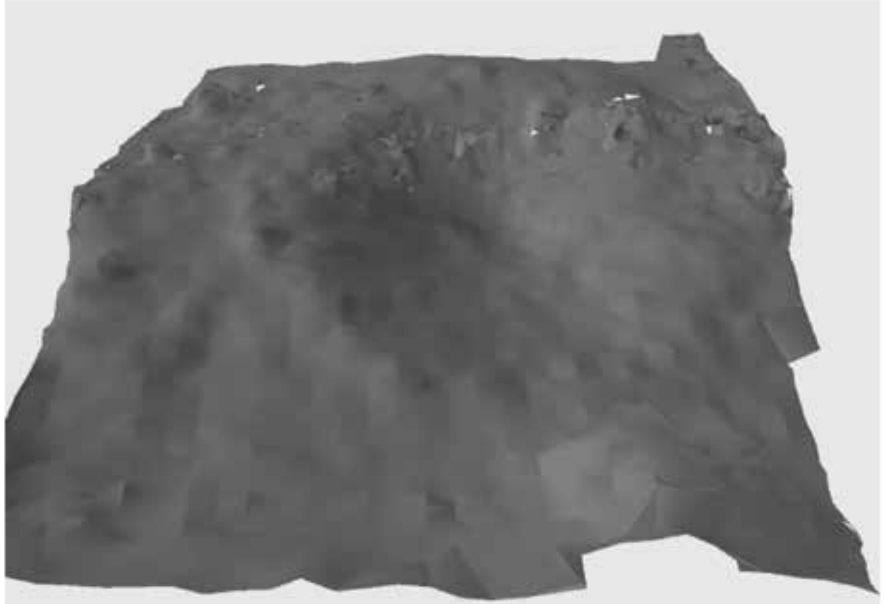
The amount of water and organics delivered to Earth via asteroids may be controlled by such dehydration due to radiogenic heat during its early history.

LIDAR (Laser Altimeter)

by Namiki

LIDAR scanned ***Ryugu topography*** covering ***equatorial bands*** between 20˚ N and 40˚ S on 2018 Jul. 20, Oct. 30, 2019 Feb. 28, Jul. 25, and Jul. 26 at an altitude lower than 7 km (below).





Urashima crater disintegrated from top shape

In order to disintegrate small scale features from top shape of Ryugu, ***topography model*** is reconstructed with respect to ***north-south symmetric longitudinal average*** (even-degree zonal harmonics of topography up to 180 degrees; *Matsumoto et al., submitted*) (above) and is currently used for geophysical studies.

TIR

Thermal Infrared Imaging

by Okada

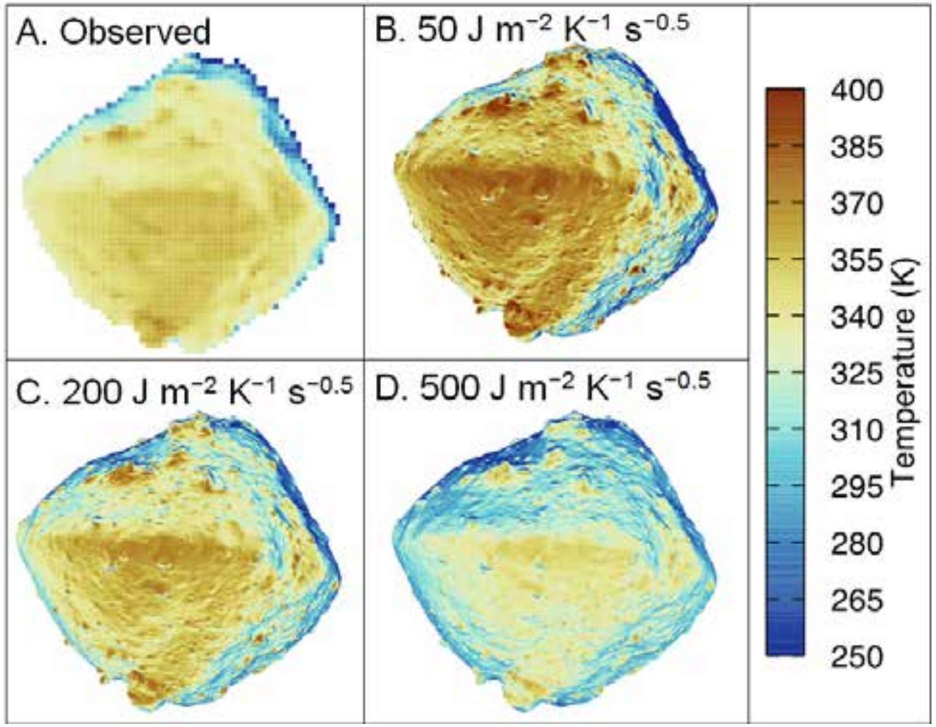
Thermal imaging by TIR obtained:

(1) The first one-rotation global thermal images of an asteroid

(2) Diurnal temperature profiles of each geologic site

(3) Phase angle dependency of thermal emissions

(4) Close-up thermal images at low altitudes



Sugita+2019 Science364, 272

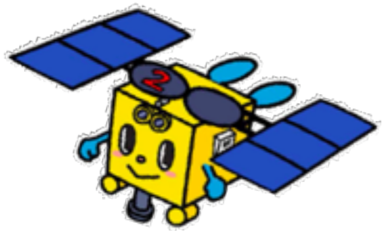
- Very low thermal inertia compared with typical carbonaceous chondrites, indicating porous materials
- Relatively flat diurnal temperature profiles probably due to a very rough surface
- Thermal inertia variation of surface boulders, suggesting different origin and formation processes

Conclusion: Achievements of Hayabusa2

◆**Seven engineering "World's Firsts"**

1. Mobile activity of rovers on small body
2. Multiple rovers deployment on small body
3. 60cm-accuracy landing and sampling
4. Artificial crater forming and observation of impact process
5. Multiple landing on extraterrestrial planet
6. Subsurface material sampling
7. Smallest-object constellation around extraterrestrial planet

Hayabusa2 will return to the earth at the end of this year.



Thank you!