Operation status for the asteroid explorer, Hayabusa2, in the vicinity of Ryugu

August 2, 2018

JAXA Hayabusa2 Project

Topics

Regarding Hayabusa2:

- Current mission status
- Science（LIDAR、NIRS3、shape model）
- Mission schedule
- Cooperative research

Note）LIDAR＝laser altimeter、NIRS3＝near-infrared spectrometer

Contents

0. Hayabusa2 & mission flow outline
1. Project status & overall schedule
2. Initial observational results with the laser altimeter
3. Initial observational results with the infrared spectrometer
4. Shape model of Ryugu
5. Mission Schedule
6. Cooperative research
7. Future plans

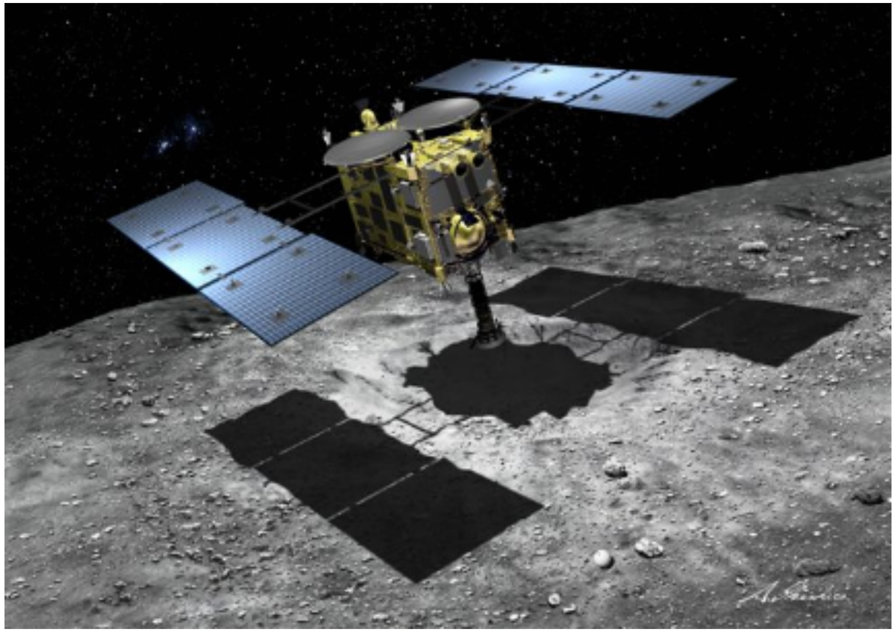
Overview of Hayabusa2

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

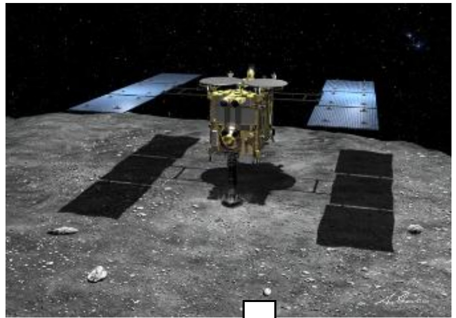
Primary instruments
Sampling mechanism, re-entry capsule, optical cameras, laser range-finder, scientific observation equipment (near-infrared, thermal infrared), impactor, miniature rovers.

Mission flow

Launch
3 Dec 2014

Earth swing-by
3 Dec 2015

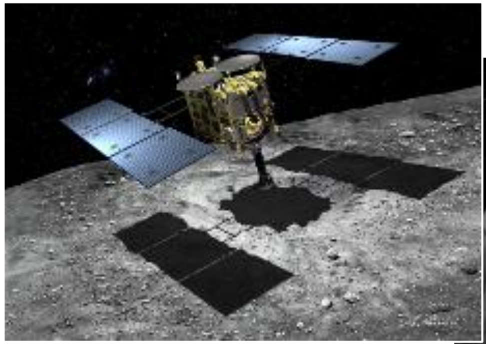
Arrival at asteroid
June 27, 2018



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

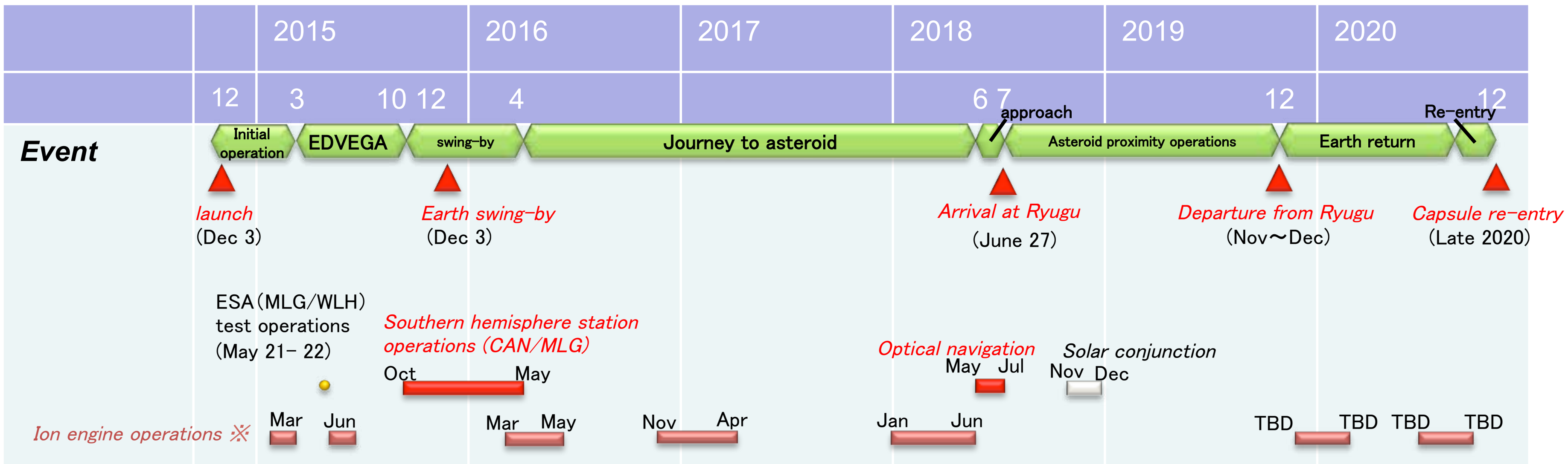
(Illustrations: Akihiro Ikeshita)

1. Current project status & schedule overview

Current status :

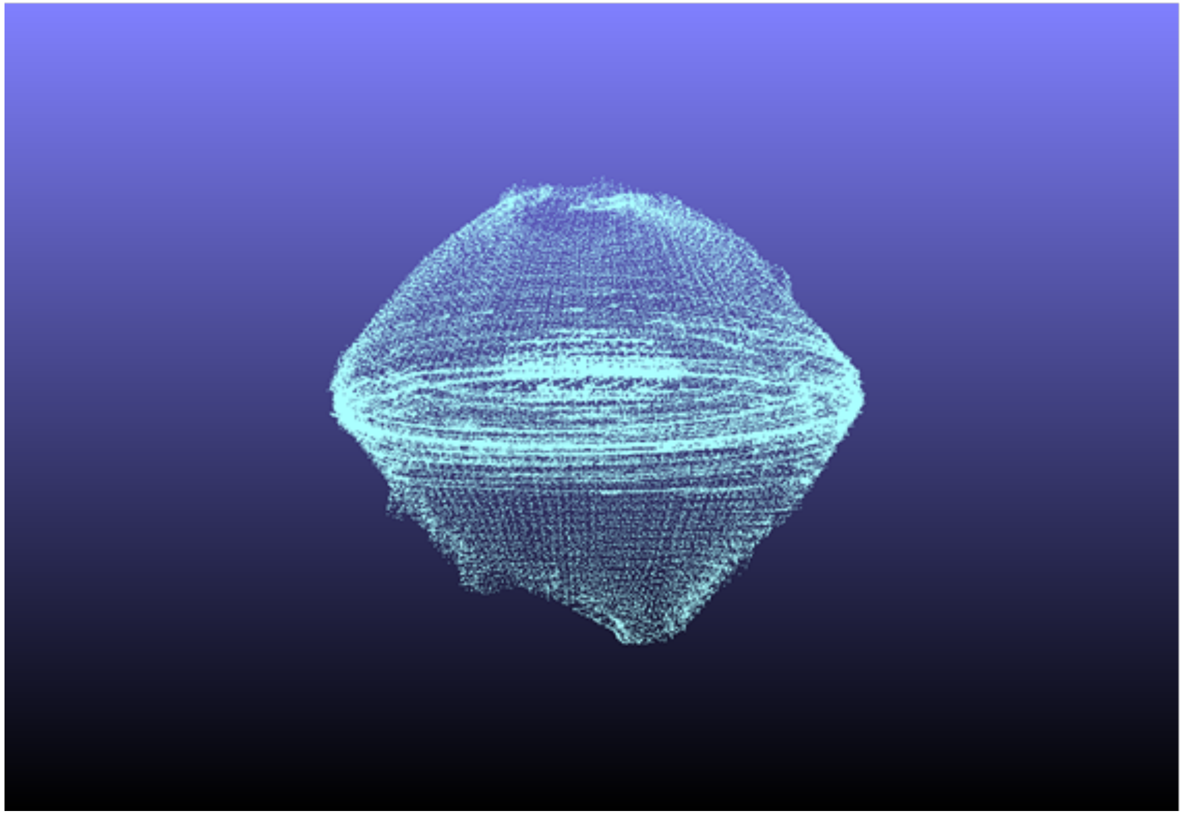
- BOX-C operations were carried out between July 17 – 25. The spacecraft remained at the lowest altitude (around 6km) for approximately one day after July 20.
- Medium altitude operations were conducted from July 31 – August 2. The spacecraft reached a minimum altitude of around 5 km on August 1.
- From August 5, we will conduct the descent operation for a gravitational measurement.

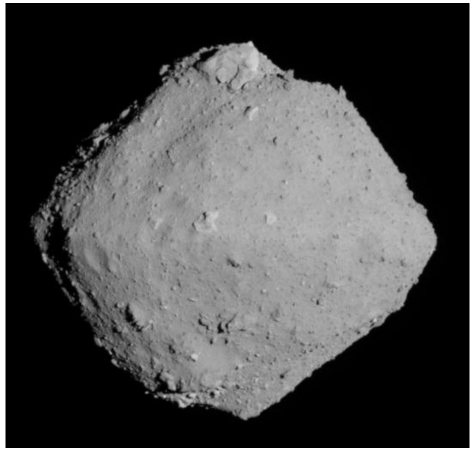
Schedule overview:



2. Initial observations with the laser altimeter

Shape measurement by LIDAR





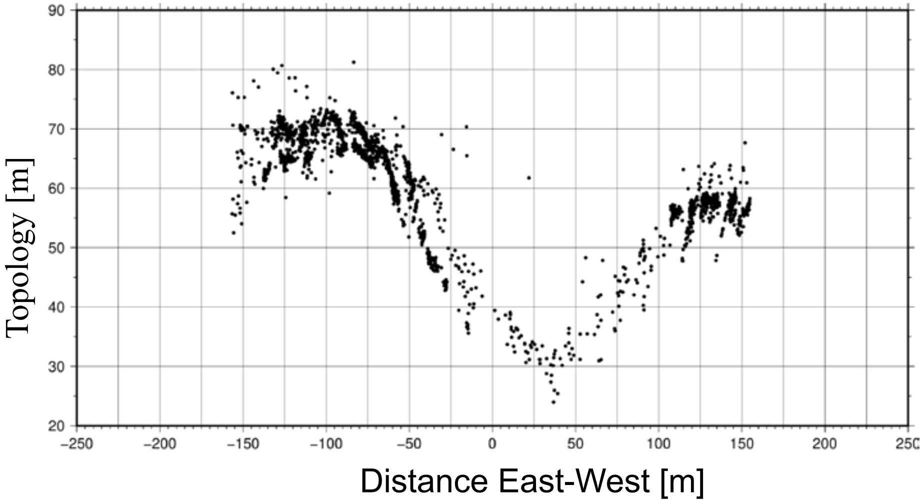
Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST

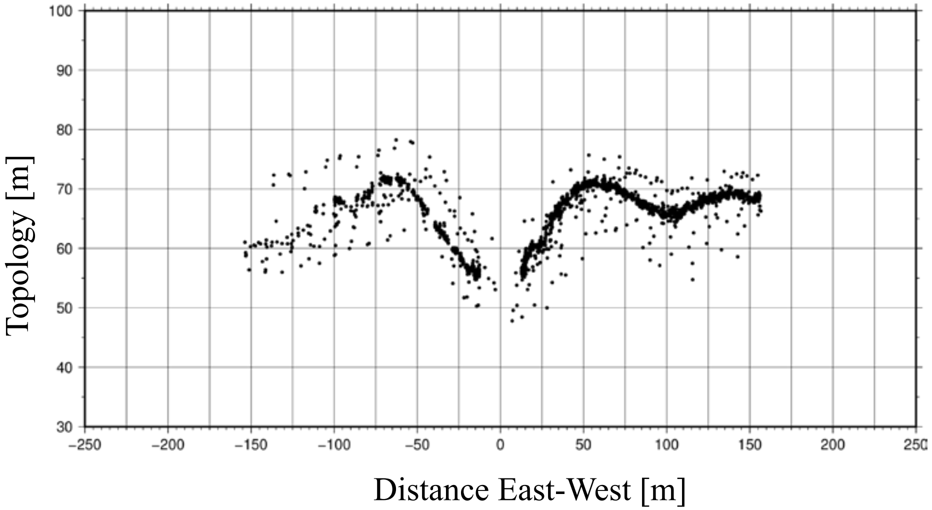
(Above) Global shape of Ryugu from laser altimeter data obtained over one month between June 30 – July 25. It nearly coincides with the shape model created from image data, with the craters and megalith readable topology. As Hayabusa2 usually hovers over the equator, there is a concentration of observations near that region

Credit: NAOJ, JAXA, Chiba Institute of Technology, University of Aizu, Nihon University, Osaka University.

2. Initial observations with the laser altimeter

Crater topology

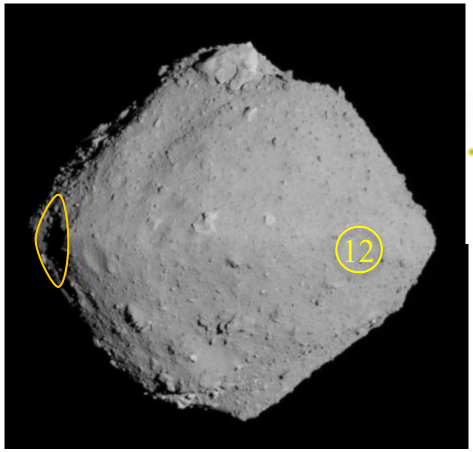




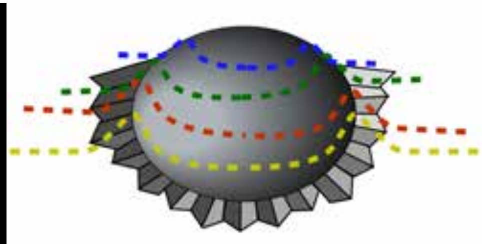
Credit: NAOJ, JAXA, Chiba Institute of Technology, University of Aizu, Nihon University, Osaka University.

(Top) Crater provision number #6. Diameter ~210m, depth ~30m. Ratio of depth to diameter is about 0.14. The height at the crater edge if 5m or less.

(Bottom) Crater provision number #12: Diameter ~ 110m, depth ~17m. Ratio of depth to diameter is about 0.16. Height a the crater edge is about 7m.



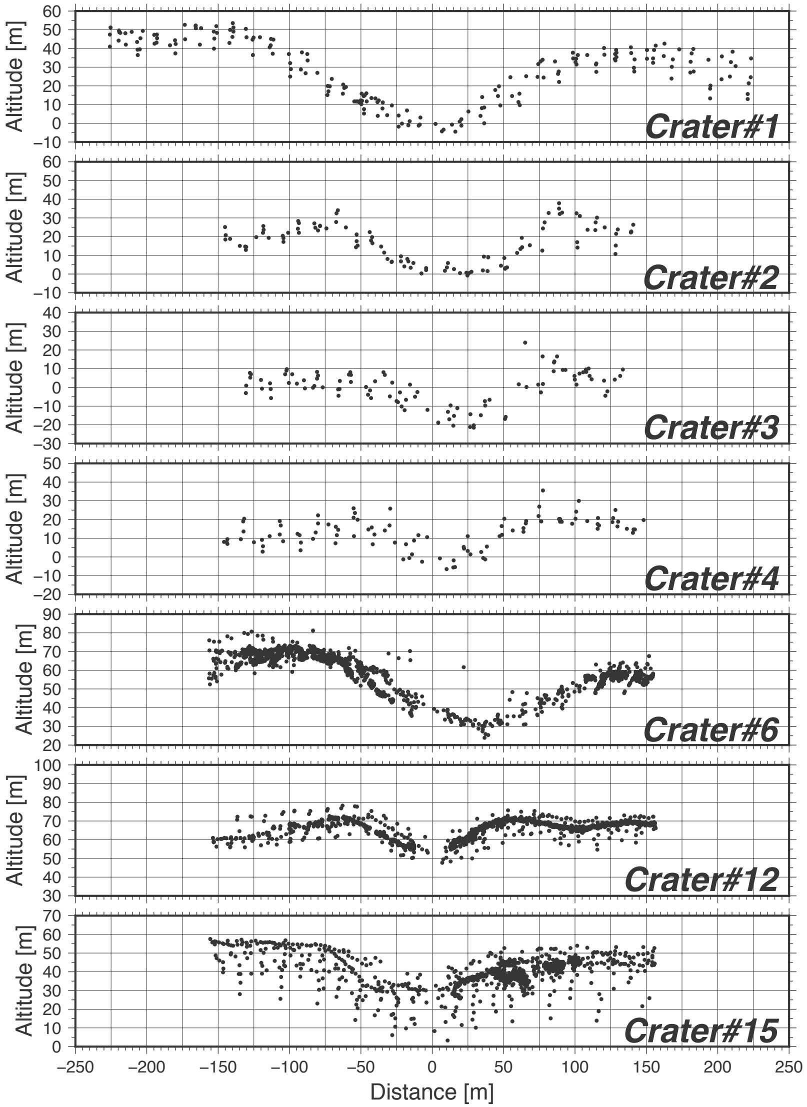
Credit: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST



The scatter of points in the left-hand figures are not due to errors, but from variations in the crater crossing position according to the position and attitude of the spacecraft

2. Initial observations with the laser altimeter

Crater topology



(East-West)

With the same method, the shape for a total of 7 craters has been measured.

From this measurement:
(i) depth/diameter ratio is about 0.1 – 0.2
(ii) There appear to be craters with relatively clear edges (about 5m high?)

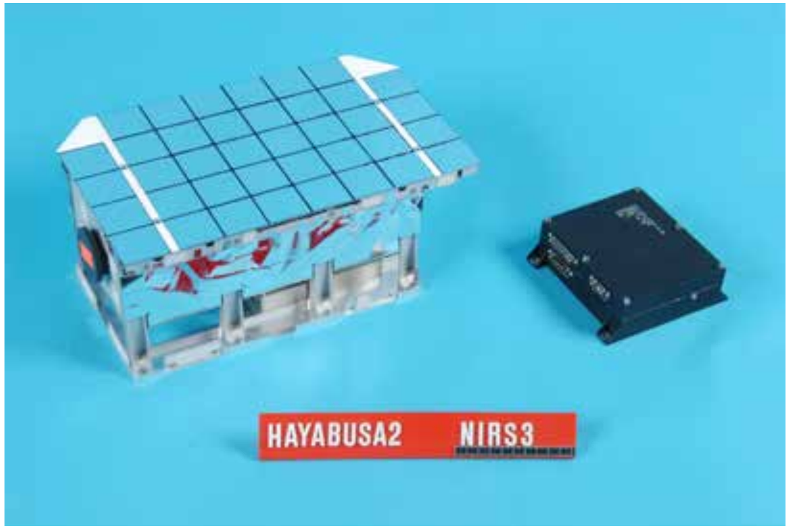
Regarding (i), this ratio is in good agreement with simple craters previously observed on asteroids and comets. On the other hand, (ii) is not a characteristic found on Itokawa (although it is not the first discovery for an asteroid/comet)

Credit: NAOJ, JAXA, Chiba Institute of Technology, University of Aizu, Nihon University, Osaka University

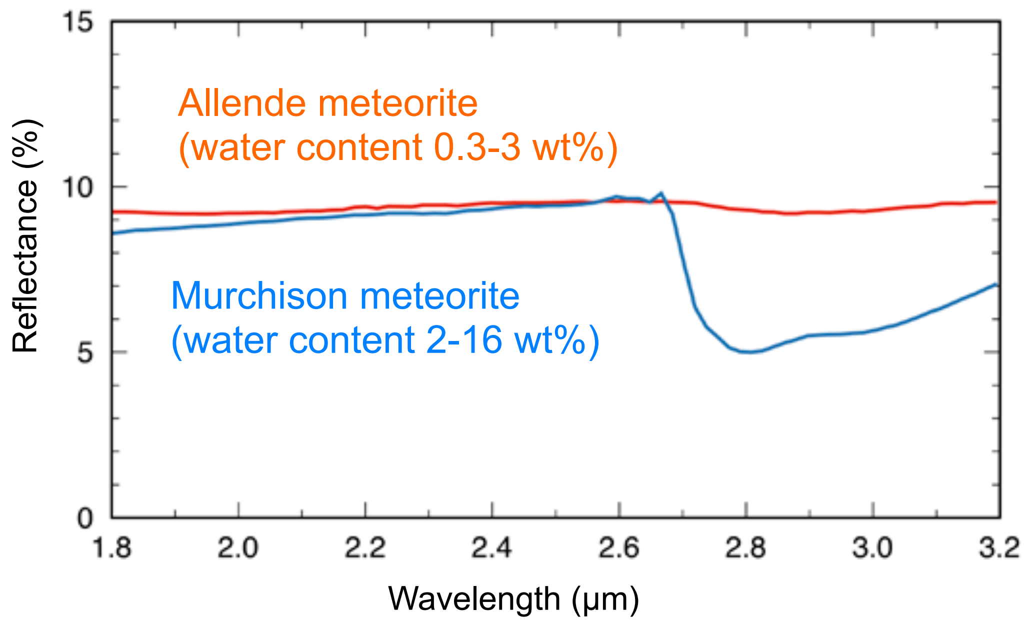
3. Initial Observations with the near infrared spectrometer

Device outline

- Observation equipment to examine the presence and distribution of moisture-containing minerals.
- The reflection spectrum in the wavelength range of 1.8 – 3.2μm is measured, along with significant absorption at 3μm by hydroxyl groups and water.



Exterior photograph



Reflectance spectrum of a carbonaceous meteorite measured in the laboratory.
Credit: Tohoku University, JAXA

Device status & observation results

- Device is operating normally with no problems in performance.
- First observations of Ryugu were successfully made on June 21, good quality data continued to be acquired.
- Since arrival on June 27, observations were taken at an altitude of 20km (Box-A) for four asteroid rotations, and at 12 – 7km (Box-C) for 2 rotations.
- Scan observations were done within Box-A and Box-C for each rotation.
- A total of approximately 54,000 spectral data points have been acquired.

Observation coverage

- Scan performed by controlling the attitude of the spacecraft and the rotation of Ryugu.
- More than 90% of the total surface was successfully observed

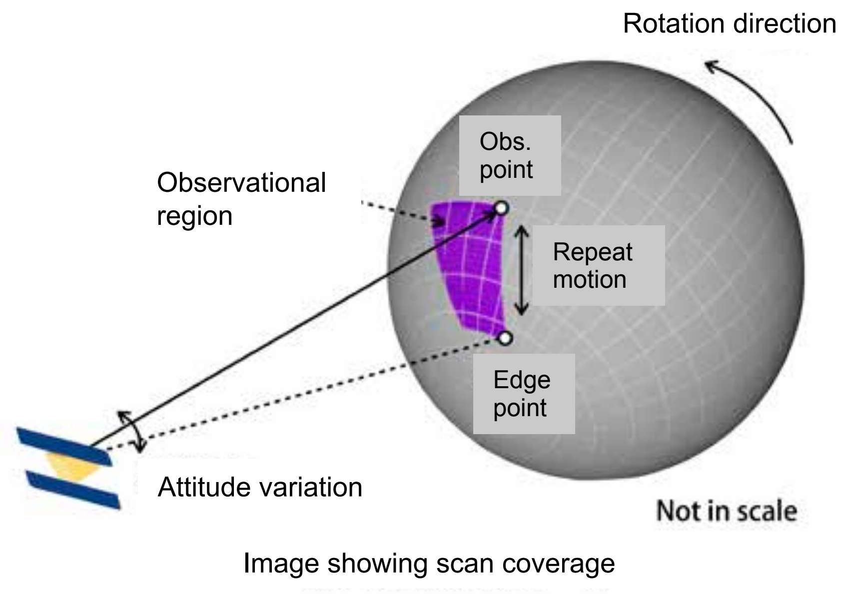
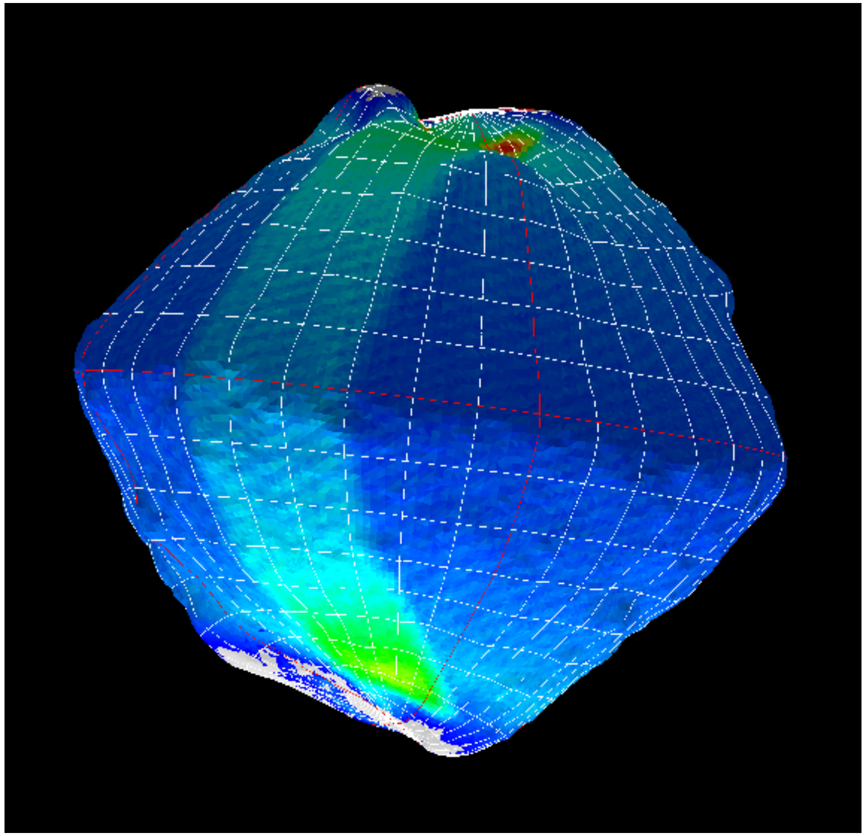


Image showing scan coverage

Credit: University of Aizu



Frequency of observations over the surface of Ryugu taken on July 11 within Box-A. Gray marks unobserved areas.
Credit: University of Aizu, JAXA

Current main results

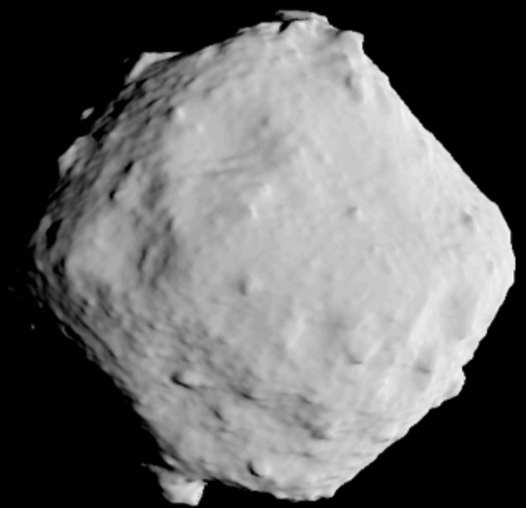
- Absorption of water at around 3μm has currently not been detected.
- The surface of Ryugu appears to be more depleted of water than expected.
- Two possible scientific interpretations:
  (1) No water-containing minerals were in the parent body
  (2) dehydration occurred during a secondary heating
- However, there is a possibility that water may exist in the polar regions or below the surface and cannot be observed. Further investigation is planned for future observations.

4. Shape Model of Ryugu

- Shape of Ryugu is estimated from the images to create a three dimension model.
  - This also gives a highly accurate estimate of the spacecraft position & attitude, as well as the rotation axis direction and period of the asteroid.
- An estimate of the asteroid size is made from the relative position of the spacecraft & asteroid and the range value from the laser altimeter.
- These two independent methods:
  - Mutually complement
  - Confirm the validity of the result by comparison between the two.
- This allows a quantitative understanding of the visible features in the image.
- Offers basic engineering information needed to determine the landing site.
- And basic physical information for considering the origins of Ryugu.

(Right) CG created shape model. Viewpoint is from 0 degrees longitude, with Ryugu's north pole at top.

SfM model, credit
University of Aizu, JAXA

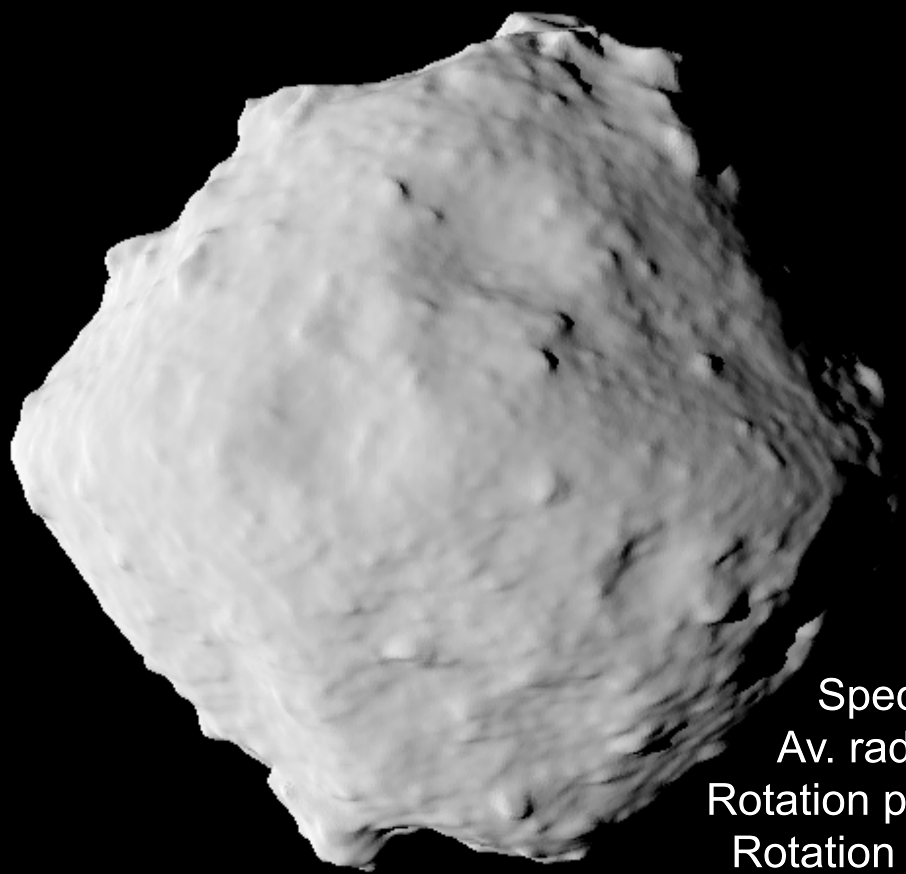


SPC model, credit Kobe
University, JAXA

4. Shape Model of Ryugu

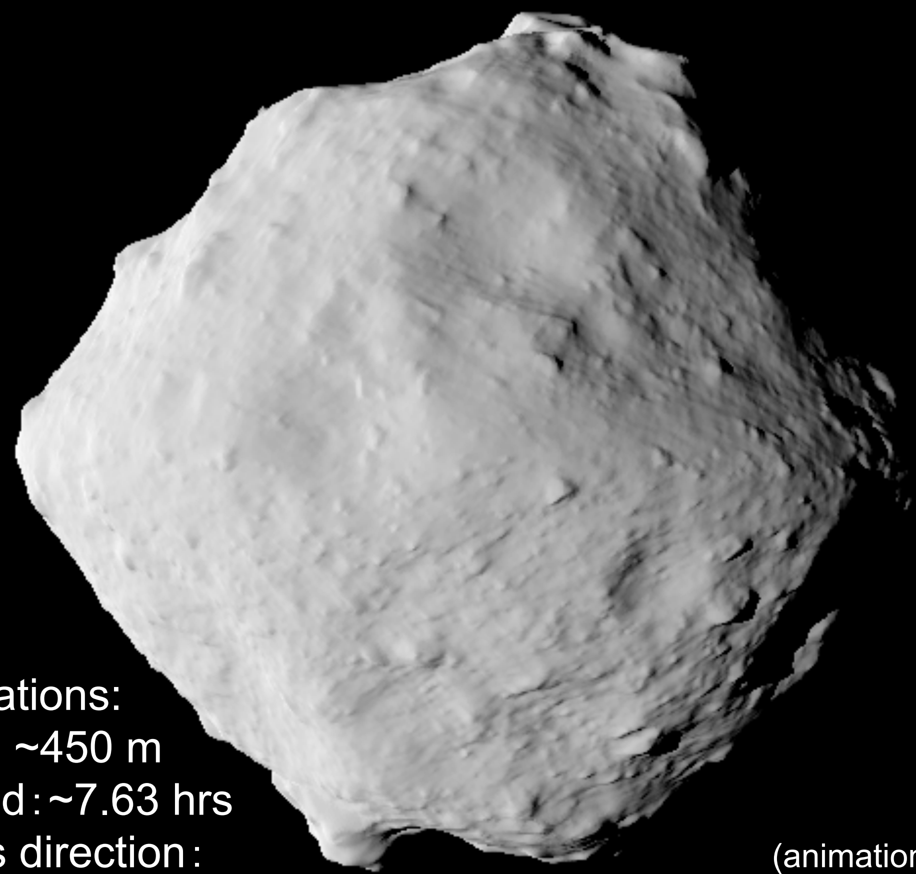
- Method of shape estimation:
  - Three-dimensional shape estimation of objects use images from multiple viewpoints (so-called stereo viewing)
- Structure-from-Motion (SfM) method:
  - Used by the analysis group at the University of Aizu
  - Almost automatic, allowing rapid processing
  - Process generalised in recent years and many different software packages now exist.
- Stereophotoclinometry (SPC) method:
  - Used by the analysis group at Kobe University
  - In addition to the stereo view, shading information generated by combining the unevenness of the terrain with the lighting conditions is also used.
  - Developed in the US for analysis of lunar and planetary exploration data.
  - Used in many exploration missions, including the shape estimate of asteroid Itokawa during the Hayabusa mission.
- We have completed the creation of the shape model mainly from images taken at a distance of 20km and are currently conducting analysis using images at higher resolution.

4. Shape Model of Ryugu



SfM model
Credit: U. Aizu, JAXA

Specifications:
Av. radius: ~450 m
Rotation period：~7.63 hrs
Rotation axis direction：
ecliptic long. Λ：~179deg
ecliptic lat. B：~ -87deg



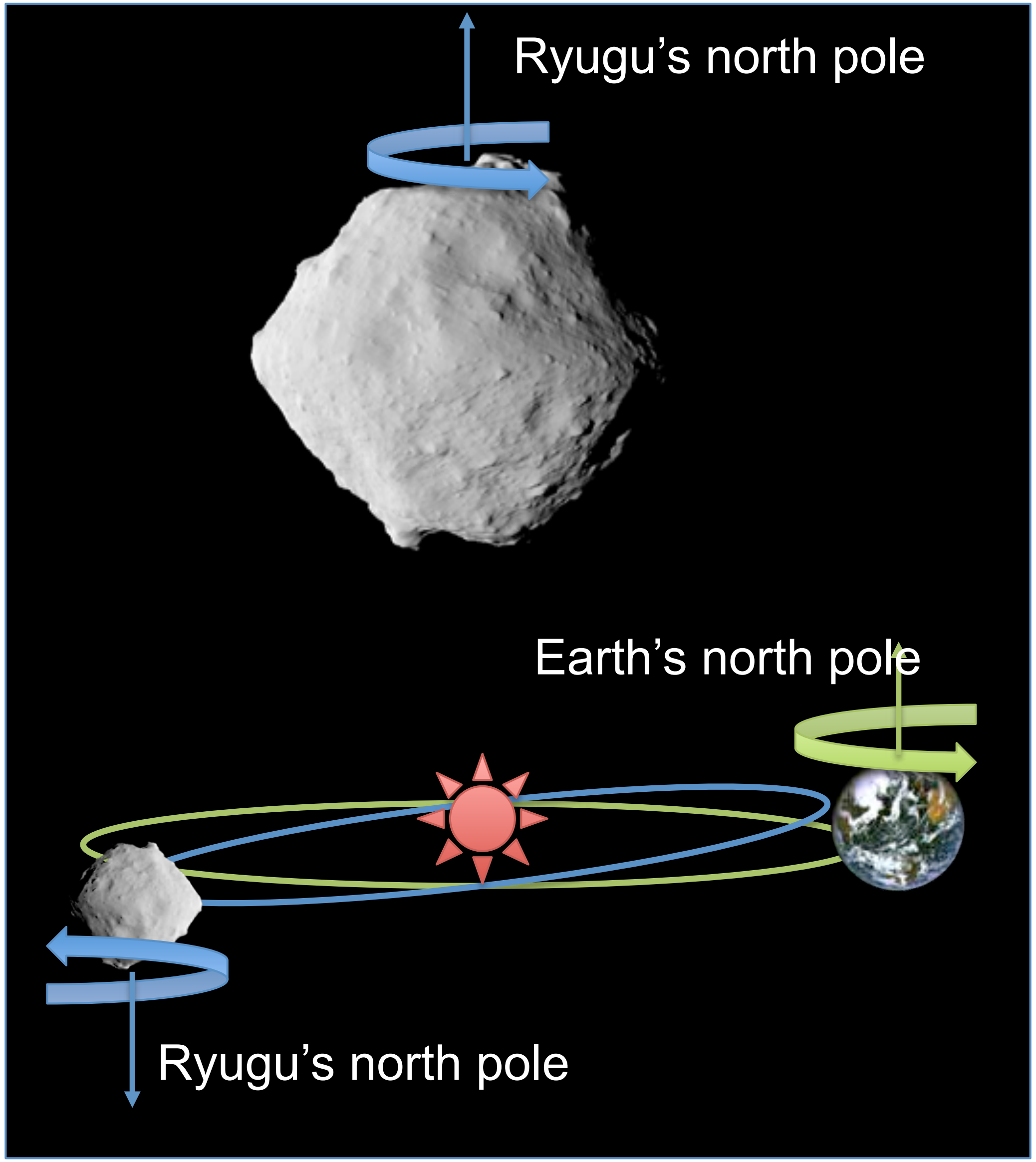
(animation)

SPC model
Credit: Kobe U, JAXA

North pole of Ryugu is at the top (opposite of previously published images)

Ryugu North-South

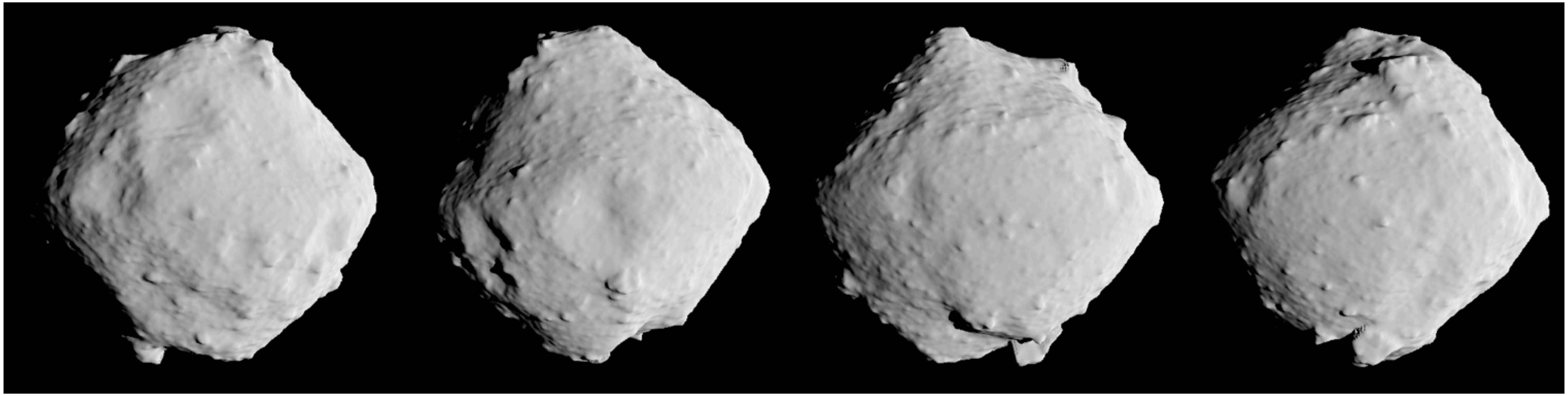
- The north & south of the asteroid depends on the direction of rotation.
- The direction of a right-hand screw (counterclockwise) is the north pole.
- The rotation is the opposite direction to the Earth.
  – Itokawa also had a reverse rotation, in the same direction as Ryugu.
- The north direction on the Earth is the standard of the north-south in the entire Solar System.
- Almost all of the images of Ryugu in the presentation material so far have been shown in the same way as the Earth's north (and that of the Solar System), with the direction upwards.



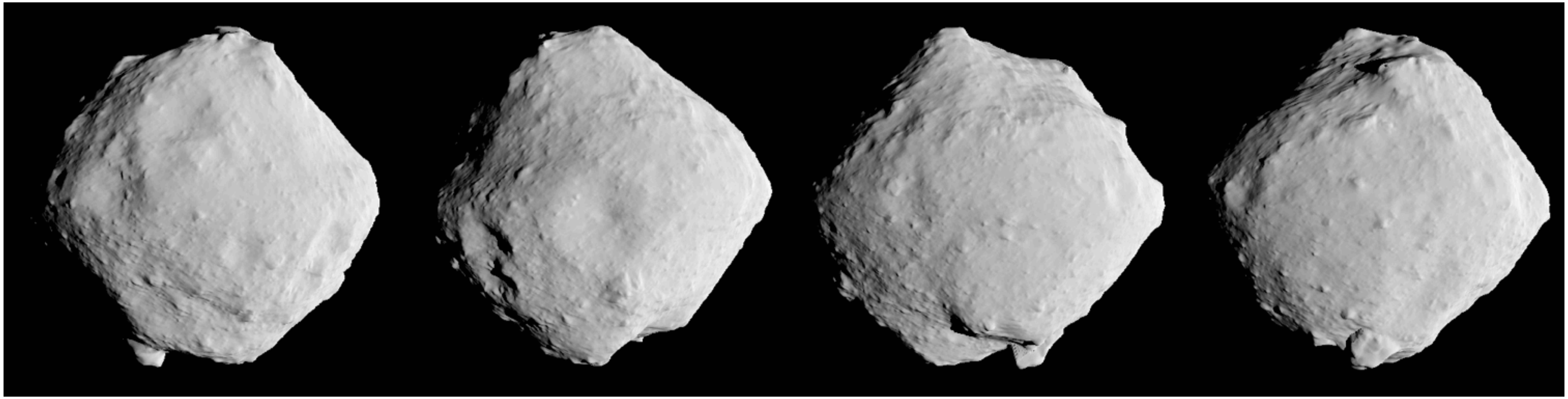
4. Shape Model of Ryugu

Four sides of Ryugu (north pole of Ryugu is top)

Longitude: 0 deg | 90 deg | 180 deg | 270 deg



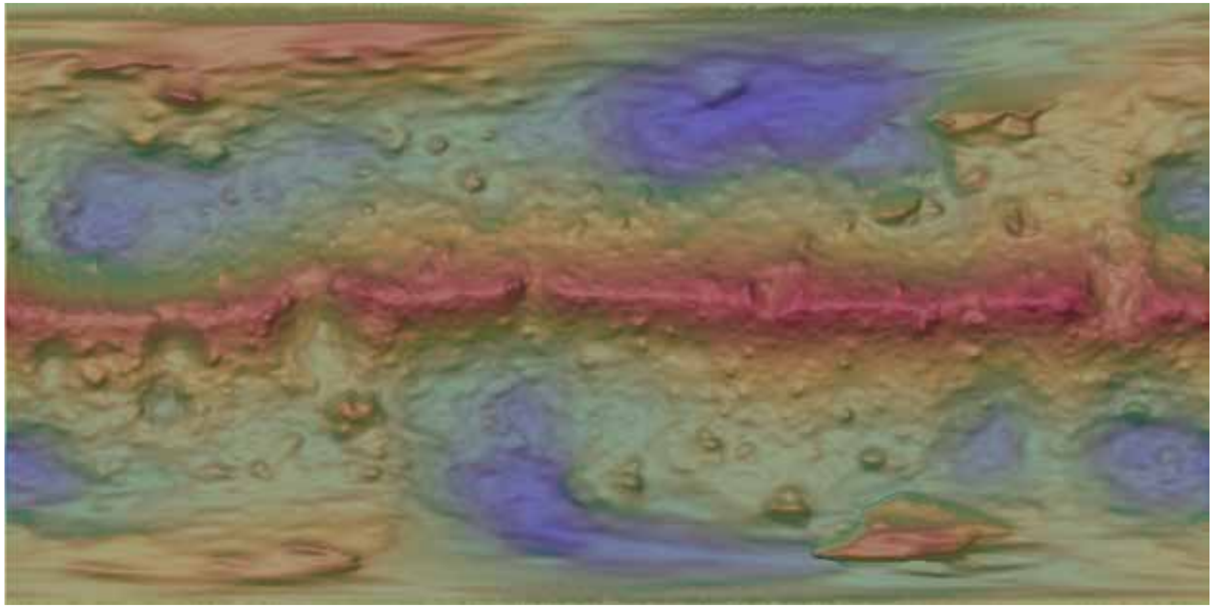
SfM model (credit: University of Aizu, JAXA)



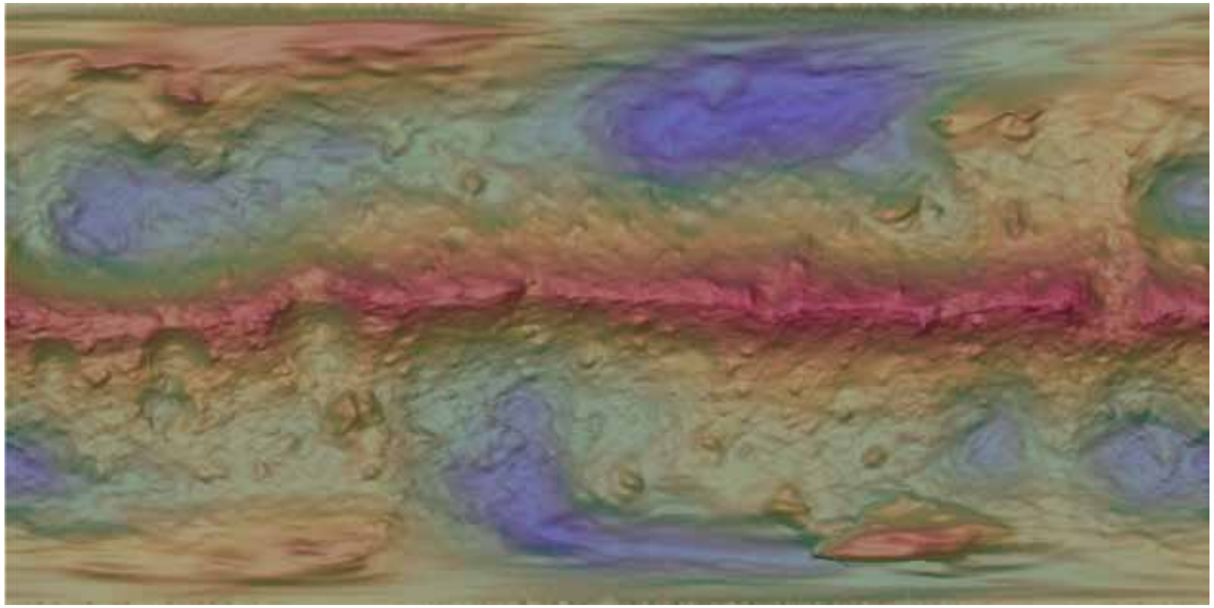
SPC model (credit: Kobe University, JAXA)

4. Shape Model of Ryugu

Map of shade on Ryugu



Created from the SfM model
(credit: JAXA. U. of Aizu)



Created from the SPC model
(credit: JAXA, Kobe U.)

5. Mission Schedule

Current operation plan

- Usual operation is from the home position of an altitude of about 20km
  ＝ BOX-A

- Operations at lower altitude

done ➢ BOX-C operations：July 17-25, lowest altitude ~ 6km (July 20-21)

on-going ➢ Medium altitude descent operation：July 31 – August 2, minimum altitude ~ 5km (Aug. 1)

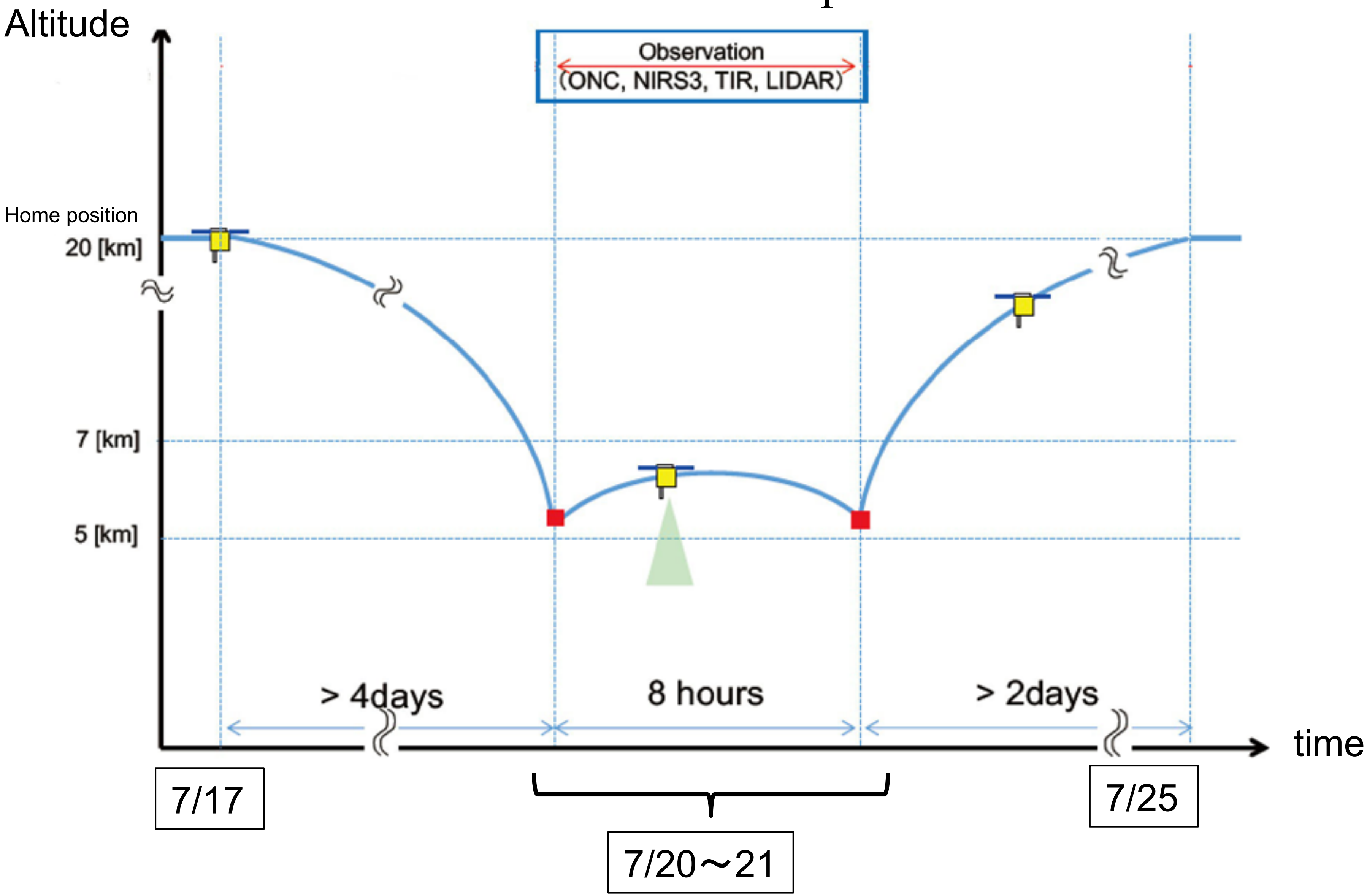
➢ Gravity measurement descent operation: August 5 – 7, minimum altitude ~ 1km (Aug. 7)

- Tour operations:
  - ➢ BOX-B operations：Late August

※ See reference material for BOX information.

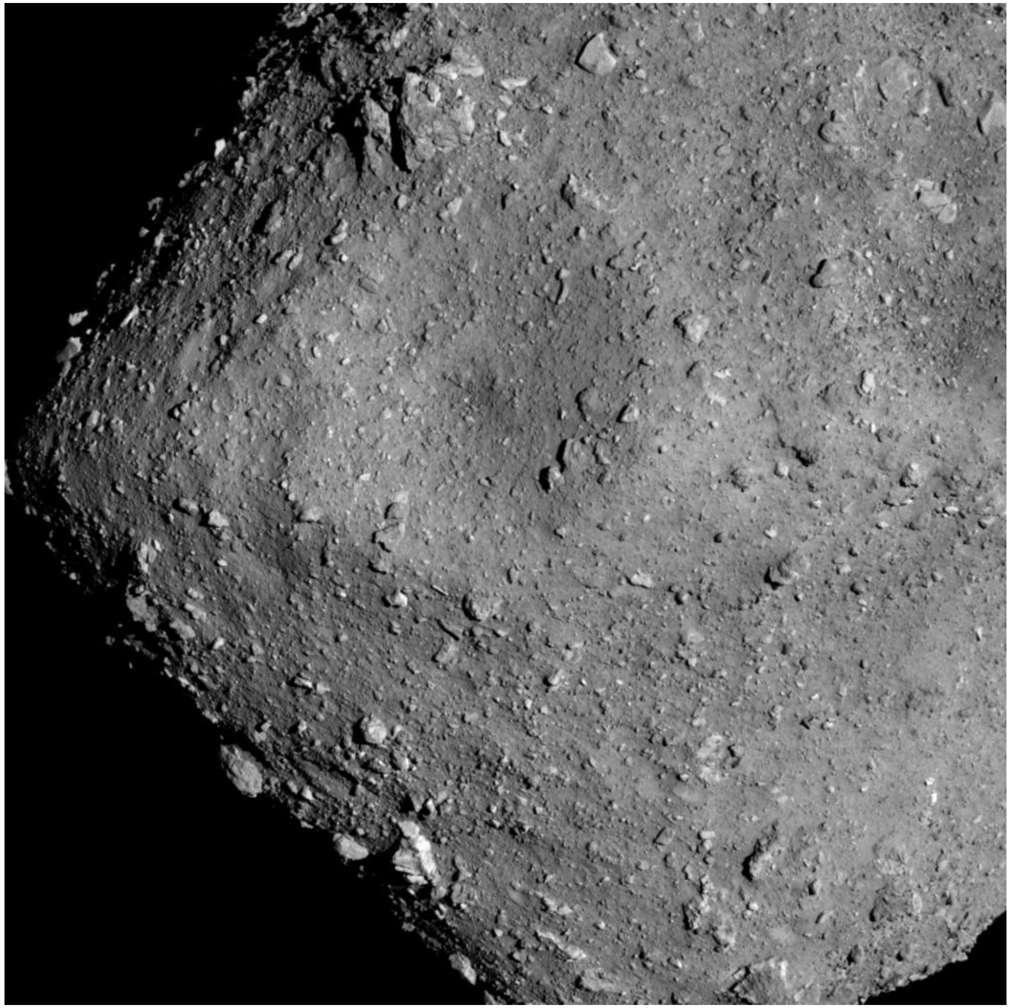
5. Mission Schedule

Outline of BOX-C operations



5. Mission Schedule

Image from BOX-C

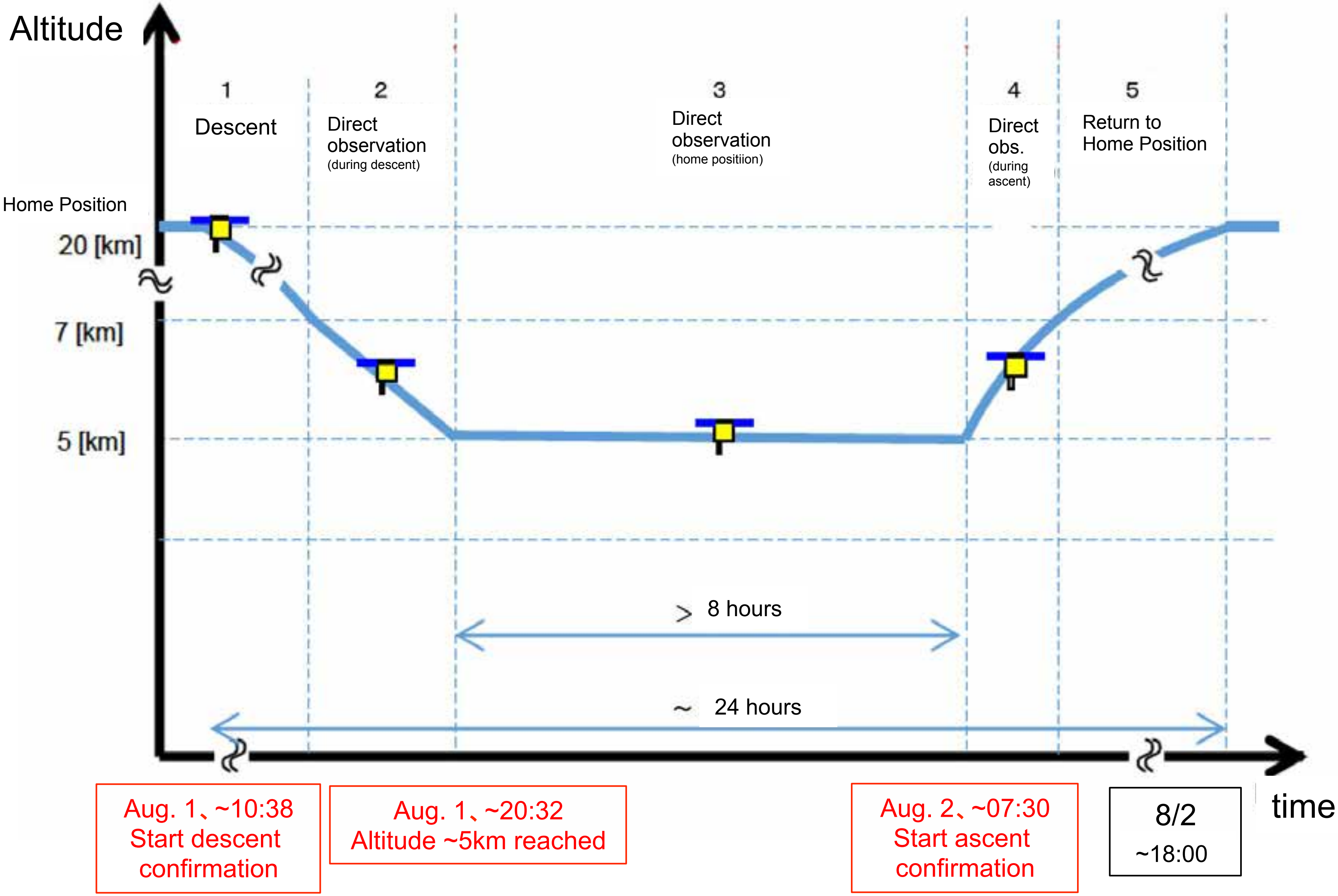


Ryugu from an altitude of ~6km. Image taken with the Optical Navigation Camera – Telescopic (ONC-T) on July 20, 2018 at around 16:00 JST.

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

5. Mission Schedule

Overview of the medium altitude descent operation



※ Time in JST. This may change depending on adjustments in the operation plan and situation

5. Mission Schedule

Overview of the medium altitude descent operation

No	Phase	Overview	Altitude
1	Descent from Home Position	Descent from Home Position. Use the same descent technique (GCP-NAV) as touchdown. NIRS3 is ON.	20～7 km
2	Direct Observations (Descending)	ONC-T, TIR observations start. Directly image surface below.	7～5 km
3	Direct Observations (Hovering)	While maintaining 5km altitude, directly image surface below.	5 km
4	Direct Observations (Ascending)	After accelerating to ascend, directly image the surface below until an altitude of 7km.	5～7 km
5	Return to Home Position	While ascending, begin the data downlink	7～20 km

※For GCP-NAV see next slide.

5. Mission Schedule

Comparison between medium height descent operation and BOX-C operation

Phase	Medium height descent	BOX-C operation
Descent time	Half-day	Descent over several days
Position control during descent	GCP-NAV	HPNAV
Position control during observations	GCP-NAV Hovering using HPNAV	Free motion depending on advanced ΔV
Observation time	8 hours	About 10 hour
Observation angle	+Z towards Earth	Scan operation implemented
Operation concept	Reduce altitude and observe at a target point and angle. (Precisely guide down to a target point in the same manner as landing)	Reduce altitude while hovering. (Approximately reduce the altitude by extending the same hovering technology)

Note：GCP-NAV (Ground Control Point Navigation)

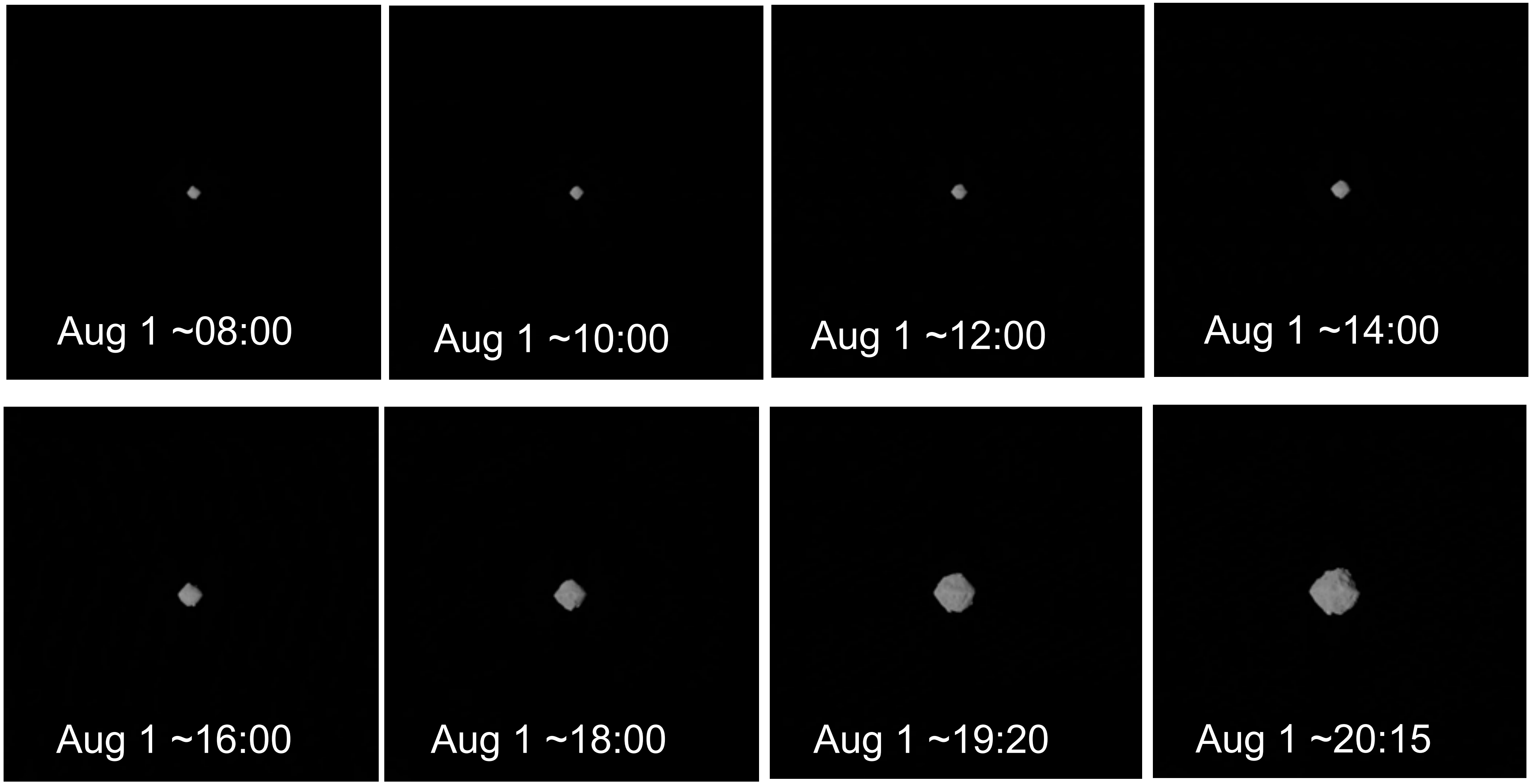
→ A method of finding the position & speed of the spacecraft by observing features on the asteroid surface.

HPNAV (Home Position Navigation)

→ A method of finding the position & speed of the spacecraft from the direction to the image center and attitude data of the spacecraft

5. Mission Schedule

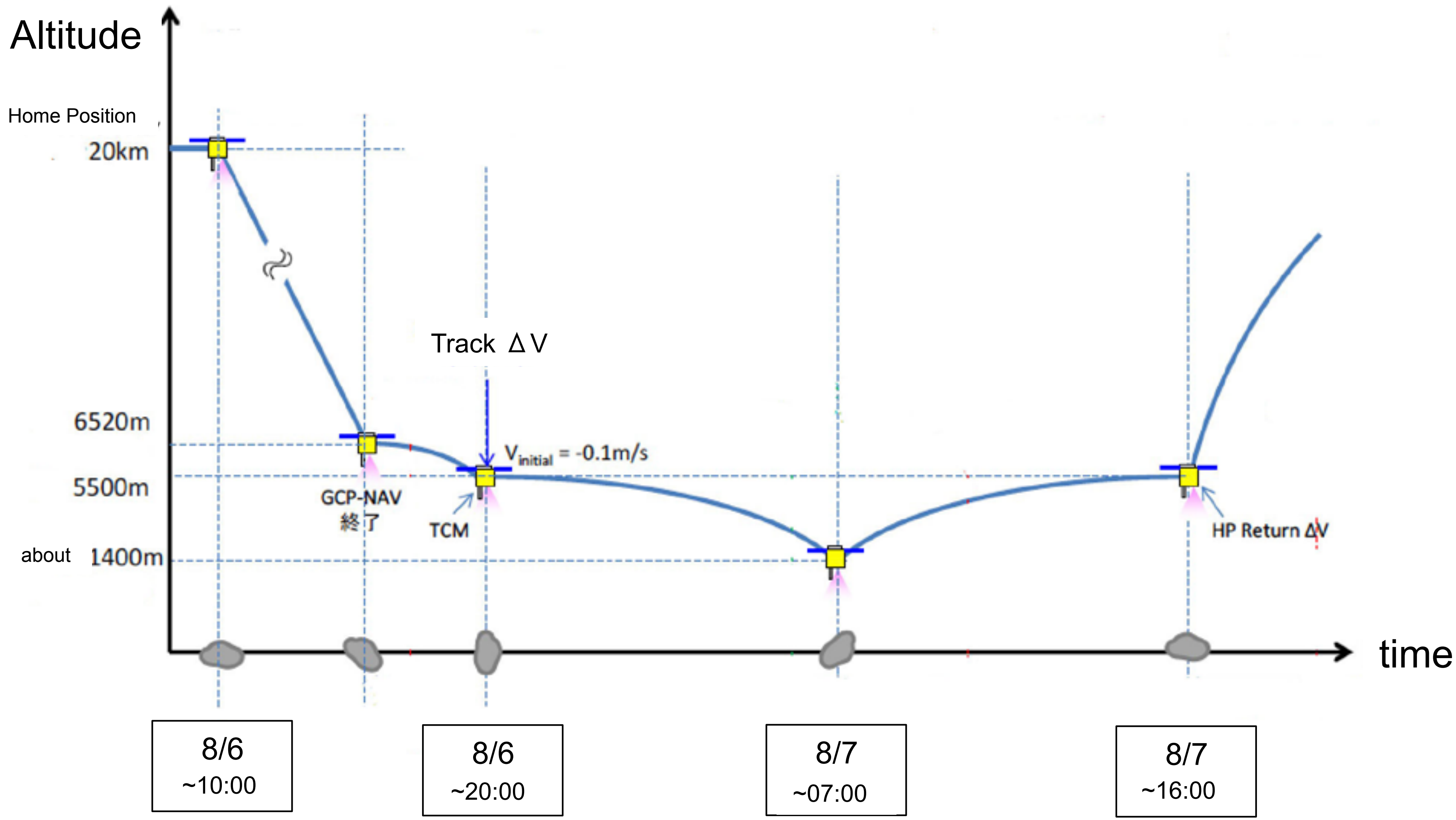
Ryugu imaged during the medium height descent operations



Images taken with the Optical Navigation Camera – Wide angle (ONC-W1). Time in JST.
(Image credit: JAXA)

5. Mission Schedule

Overview of gravity measurement descent operation



※ Time in JST. This may change depending on adjustments in the operation plan and situation

5. Mission schedule

Year	Month, day	Event	Status
2018	January 10	Third stage of ion engine operation begins	Complete
	June 3	Ion engine operation ends	Complete
	June 3	Start of asteroid approach (distance: 3100km)	Complete
	June 27	Arrival at asteroid Ryugu (altitude 20km)	Complete
	End of July	Medium altitude observations #1 (alt. 5km)	Planning
	August	Decent to measure gravity (alt.1km)	Planning
	Late August	Determination of landing site	Planning
	Sept – Oct	Period for touchdown operation #1	Planning
	Sept – Oct	Period for rover deployment #1	Planning
	Nov – Dec	Solar conjunction (communication unavailable)	Planning
2019	January	Medium altitude observations #2 (alt. 5km)	Planning
	February	Period for touchdown operation #2	Planning
	Mar – Apr	Crater generation operation	Planning
	Apr – May	Period for touchdown operation #3	Planning
	July	Period for rover deployment #2	Planning
	Aug – Nov	Remain near asteroid	Planning
	Nov – Dec	Departure from asteroid	Planning

This schedule may be changed for multiple factors after arrival at Ryugu. Please note therefore, that the situation is not fixed, except where marked 'Complete'.

6. Cooperative research

■Cooperative research with Space Exploration Innovation Hub Center of JAXA:

- The technique of Visual SLAM (Simultaneous Localization and Mapping) is being developed at the Space Exploration Innovation Hub Center of JAXA.
- We try to apply this technique to the operation of Hayabusa2.

■Research teams

(1) IVIS Corp. and ViewPLUS Corp.

http://www.ivis.co.jp http://www.viewplus.co.jp

(2) Concept Corp. and Morpho Corp.

https://qoncept.co.jp https://www.morphoinc.com

(Please see the material in Japanese for detailed information.)

7. Future Plans

■Schedule of press briefings

- Aug. 23（Thurs）16:30～17:30
- Sept. 5（Wed）11:00～12:00
- Sept. 27（Thurs）14:30～15:30

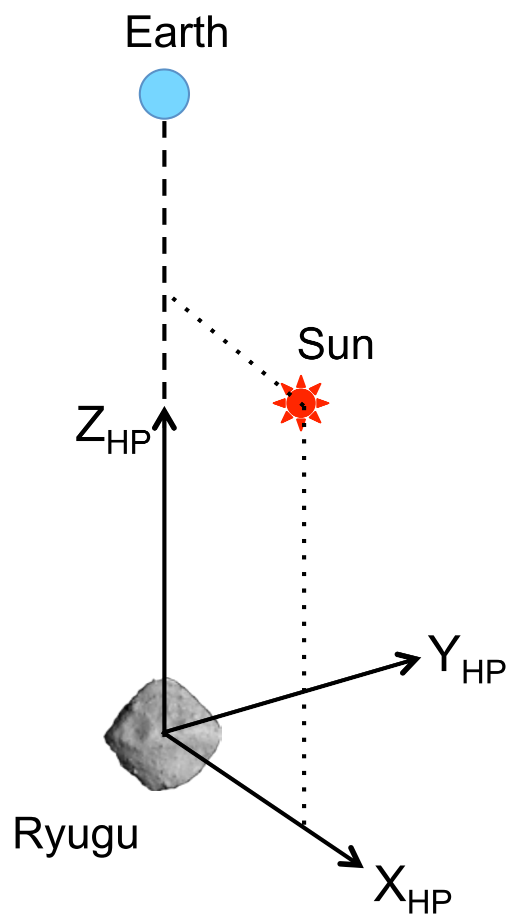
■Outreach and events (in Japanese)

➢ Events for Children

- Why Hayabusa2? Any questions classroom
- Sept. 2 (Sunday) 2 – 4pm
- Sagamihara City Museum
- Online broadcast planned

Reference material

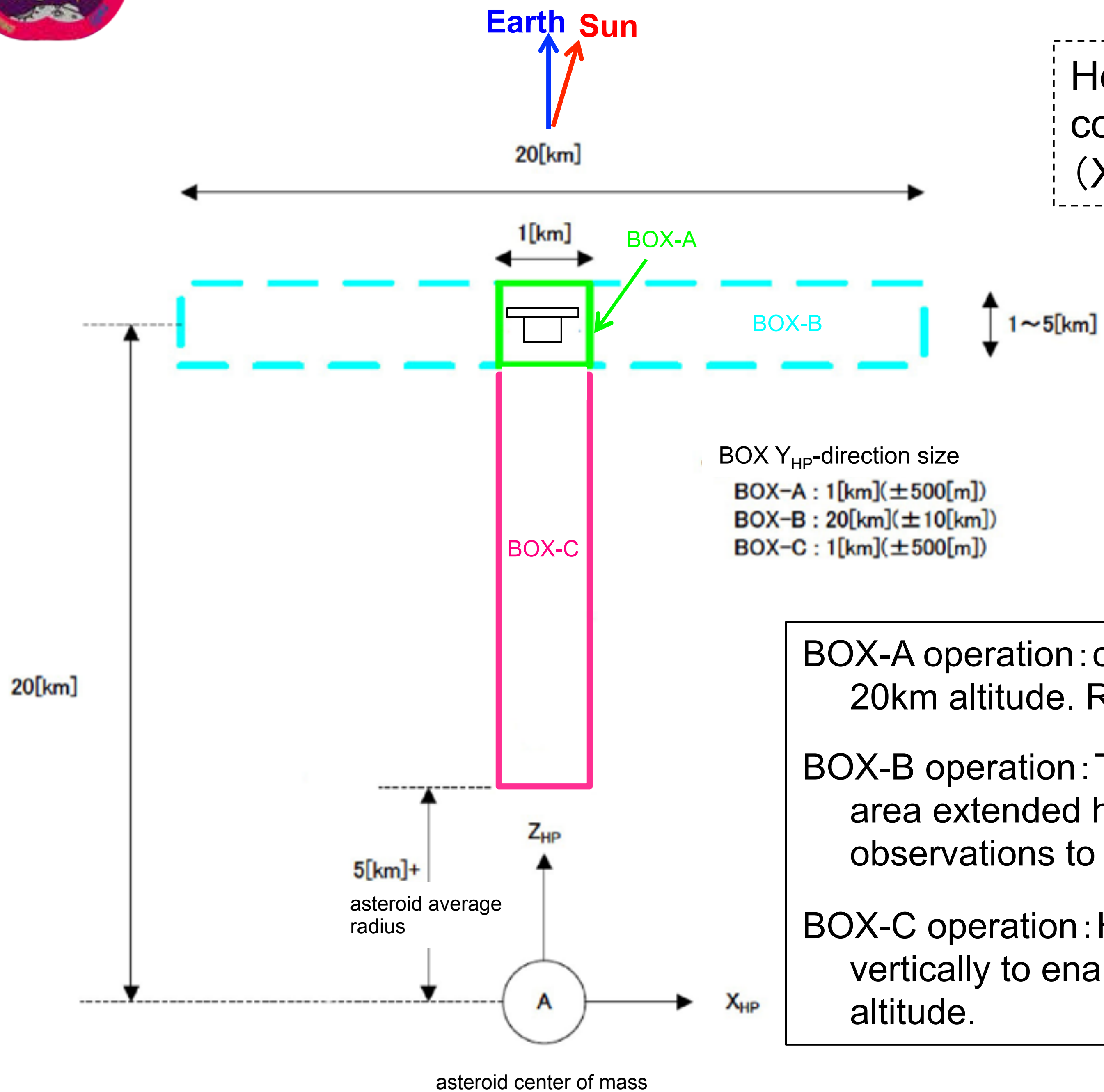
Home Position Coordinate System



BOX definition

Home position coordinate system (X_{HP}, Y_{HP}, Z_{HP})

(Reference material)

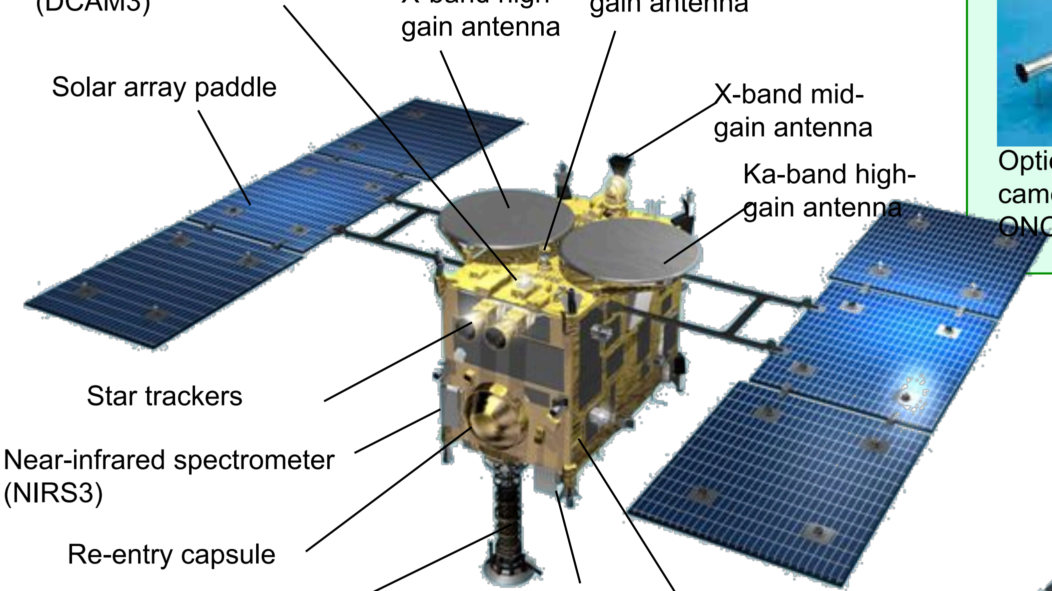


BOX-A operation : operations while hovering at 20km altitude. Regular operation standard.

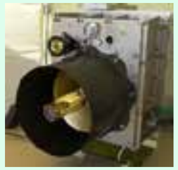
BOX-B operation : Tour observation. Hovering area extended horizontally to enable observations to either side of the asteroid.

BOX-C operation : Hovering area extended vertically to enable observations at low altitude.

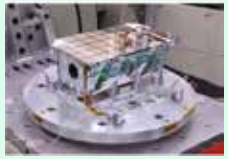
Primary spacecraft components



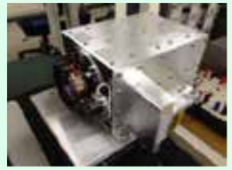
Optical navigation camera ONC-T



Laser altimeter LIDAR



Near-infrared spectrometer NIRS3



Thermal infrared camera TIR

Scientific observation equipment

Small lander & rover

MASCOT

Created by DLR and CNES

Minerva 2

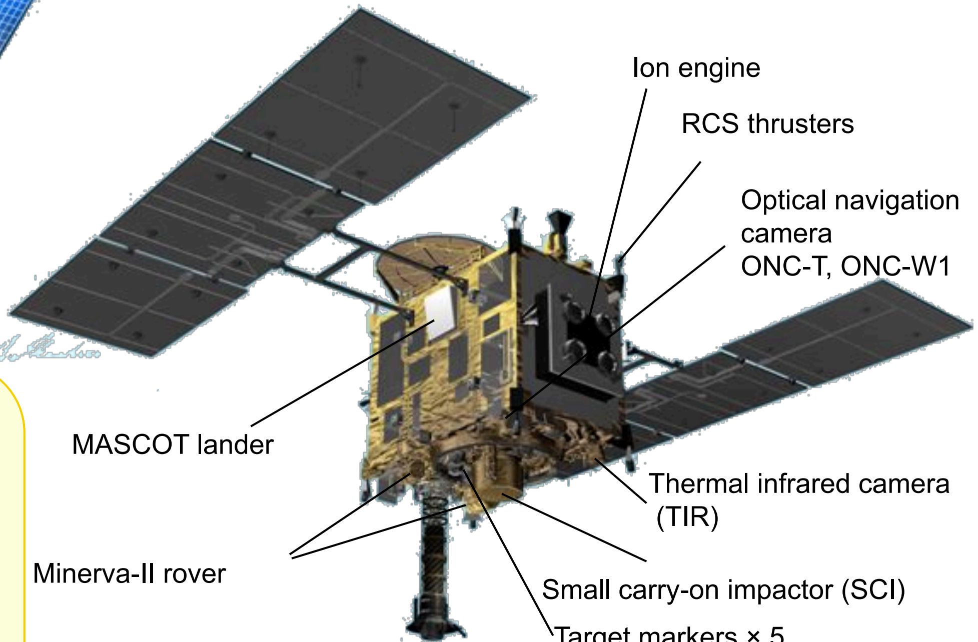
II-1A

II-1B

II-2

II-1: By the JAXA Minerva-II team

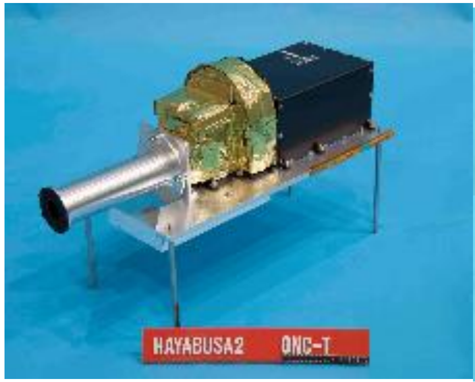
II-2: By Tohoku Univ. & the Minerva-II Consortium

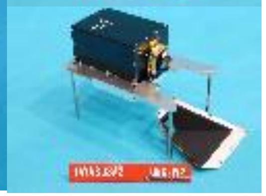


Size： 1 ×1. 6×1. 25 m (main body)
Solar paddle deployed width 6 m
Mass ： 609 kg (incl. fuel)

Remote sensing equipment

Optical Navigation Camera (ONC)

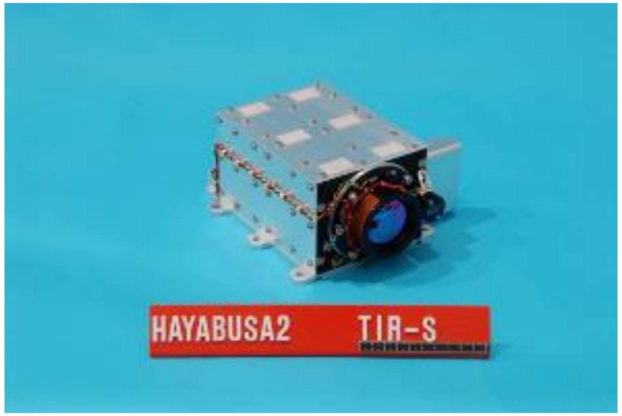


ONC-T (telephoto)　ONC-W1,W2 (wide-angle)

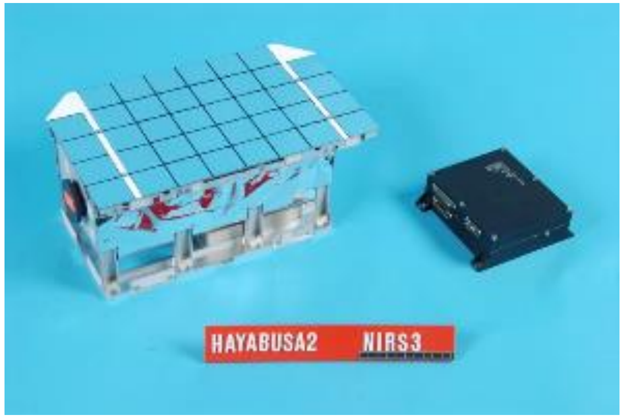
Imaging for scientific observation and navigation

Thermal Infrared Camera (TIR)



8–12 μm imaging: Measures asteroid surface temperature

Near-infrared Spectrometer (NIRS3)



Infrared spectra including the 3-μm band: investigates mineral distributions on the asteroid surface

Laser Altimeter (LIDAR)

Measures distance between the asteroid and the spacecraft in a range of 30 m–25 km

Optical navigation camera (ONC)

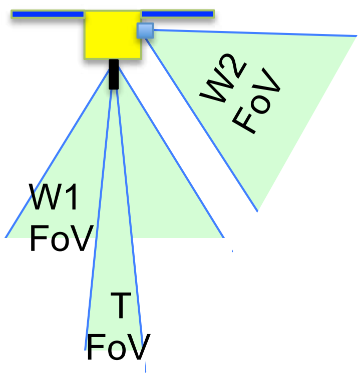
ONC : Optical Navigation Camera

<u>Objective:</u> Images fixed stars and the target asteroid for spacecraft guidance and scientific measurements

<u>Scientific measurements :</u>

- 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

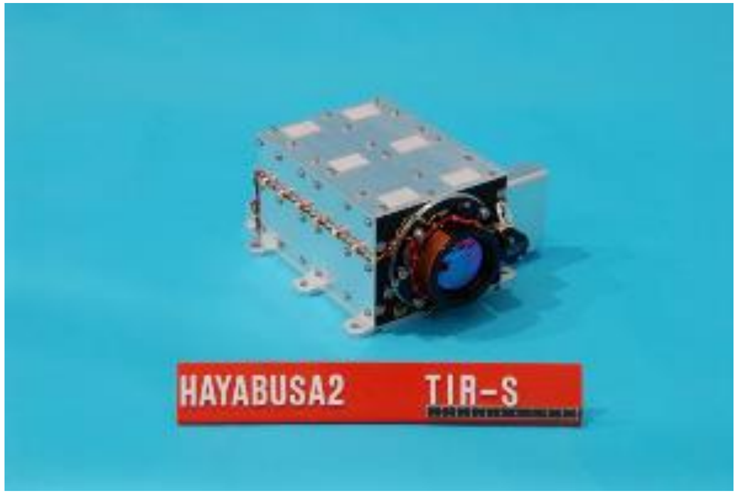


	ONC-T	ONC-W1	ONC-W2
Detector	2D Si-CCD (1024 × 1024 px)		
Viewing direction	Downward (telephoto)	Downward (wide-angle)	Sideward (wide-angle)
Viewing angle	6.35° × 6.35°	65.24° × 65.24°	
Focal length	100 m–∞	1 m–∞	
Spatial resolution	1 m/px @ 10-km alt. 1 cm/px @100-m alt.	10 m/px @10-km alt. 1 mm/px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

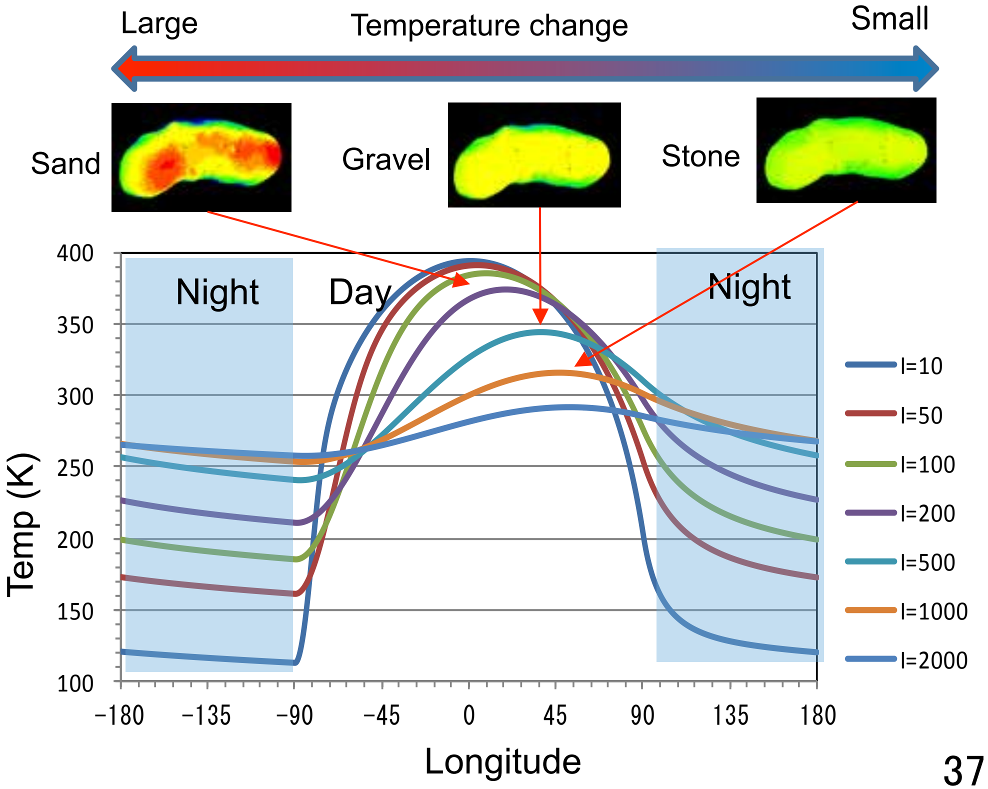
Thermal infrared camera (TIR)

TIR=Thermal Infrared Imager

The surface temperature of the asteroid changes over the day, rising in sunlight and decreasing at night. Diurnal change in surface temperature is large in fine soils like sand and highly porous rock, and small in dense rock.
We will examine the physical state of the asteroid's surface by 2D imaging (thermography) of thermal radiation from the asteroid.



・Detector	: 2D uncooled bolometer
・Observation wavelength	: 8–12 µm
・Observed temperatures	: –40 to 150 °C
・Relative accuracy	: 0.3 °C
・Dimensions	: 328 × 248 (effective)
・Viewing angle	: 16°×12°
・Resolution	: 20 m (20-km alt.) 5 cm (50-m alt.)

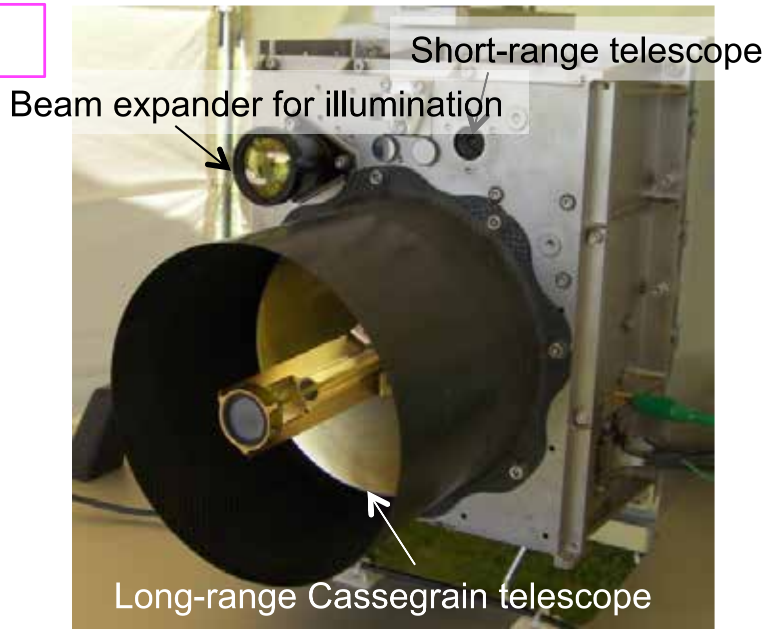


Laser altimeter (LIDAR)

LIDAR: Light Detection And Ranging

- Pulse-type laser altimeter
- A pulse YAG laser with a 1.064-μm wavelength is emitted toward the target object, and the altitude is measured by measuring the return time of the laser beam.
- The LIDAR aboard Hayabusa 2 could perform measurements from 30 m–25 km.

- LIDAR is a navigation sensor used for approach and landing at a target, and a scientific observation device used to measure shape, gravity, and surface characteristics, and for dust observations.
- It also has a transponder function that can perform space laser ranging (SLR) experiments with ground LIDAR stations.



Laser altimeter engineering model

Scientific objectives

- Terrain and gravity field observations of the target asteroid
- Observations of albedo distribution at various surface points
- Observations of dust floating around the asteroid

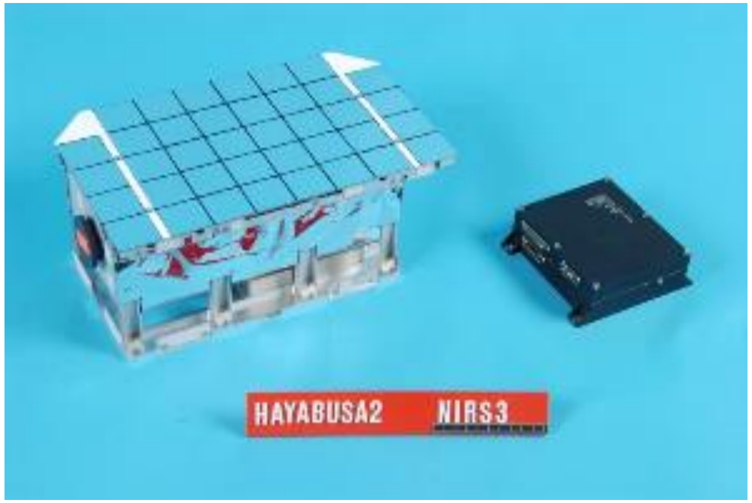
↓

- Asteroid form, mass, porosity, and deviation
- Asteroid surface roughness
- Dust floating phenomena

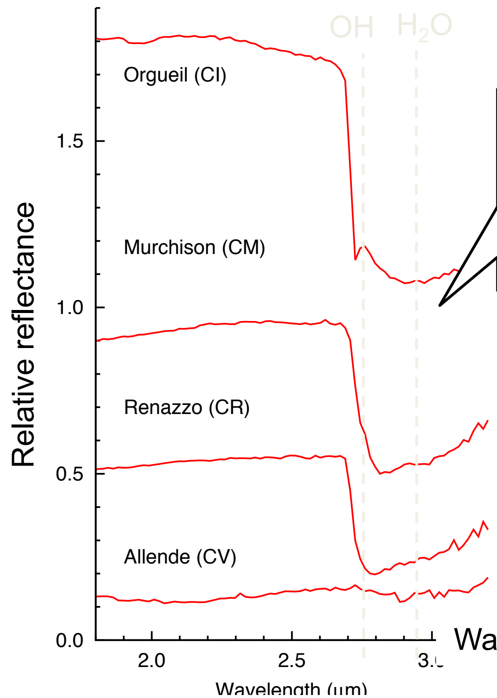
Near-infrared spectrometer (NIRS3)

NIRS3: Near-infrared Spectrometer
('3' from 3 µm)

Infrared absorption of hydroxyl groups and water molecules is observed in 3-µm band reflection spectra in the near-infrared region. NIRS3 investigates distributions of hydrous minerals on the asteroid surface by measuring reflection spectra in the 3-µm band.



- Observation wavelength range: 1.8–3.2 µm
- Wavelength resolution: 20 nm
- Full field of view: 0.1 deg
- Spatial resolution: 35 m (20-km alt.)
  2 m (1-km alt.)
- Detector temperature: –85 to –70 °C
- S/N ratio: 50+ (wavelength 2.6 µm)



Absorption form and depth vary depending on the type and amount of hydrous mineral

Wavelength (µm)

Near-infrared reflection spectra of carbonaceous chondrites