Current status of the asteroid explorer, Hayabusa2, leading up to arrival at asteroid Ryugu in 2018

June 14th, 2018

JAXA Hayabusa2 Project

Today's Topics

For the Hayabusa2 spacecraft:

- Observation of Ryugu
- Optical Navigation (Hybrid navigation using optical and radiometric observations)
- Search for satellites
- Schedule

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1. Current status and project schedule
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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	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 altimeter, scientific observation equipment (near–infrared, thermal infrared), impactor, small rovers

Outline of mission flow

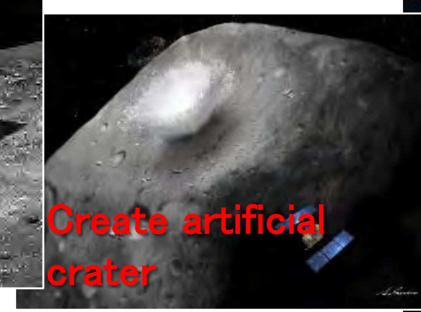
Launch
December 3rd, 2014

Earth swing-by
December 3rd, 2015

Asteroid arrival
June 27th, 2018 (planned)

Examination of asteroid via remote sensing observations, followed by the release of the small lander and rovers. Obtain samples from the asteroid surface.

Create an artificial crater on the asteroid surface using an impact device.



Departure from the asteroid
November – December, 2019

After confirming site safety, touchdown to the crater to collect subsurface material

Return to Earth
End of 2020

Sample analysis

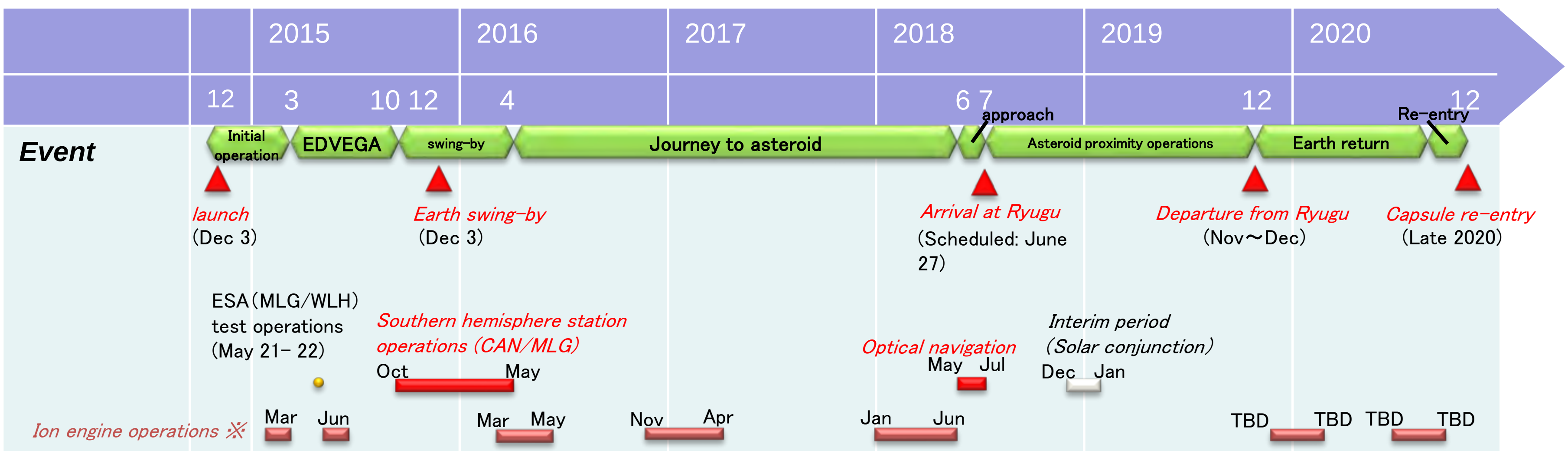
(Illustration: Akihiro Ikeshita)

1. Current status and project schedule

Current status：

- The distance between Ryugu and the spacecraft is about 750km today (June 14)
- Today, we will perform a Trajectory Correction Maneuver (TCM03). Approximate approach speed of Hayabusa2 after TCM03 is 1.7 m/s.
- Optical navigation will be used until arriving at Ryugu
- We are currently observing the light curve of Ryugu and searching for satellites.
- Arrival at Ryugu is scheduled for around June 27.

Schedule overview：



1. Observation of Ryugu

■Optical navigation cameras（ONC-T、ONC-W1）

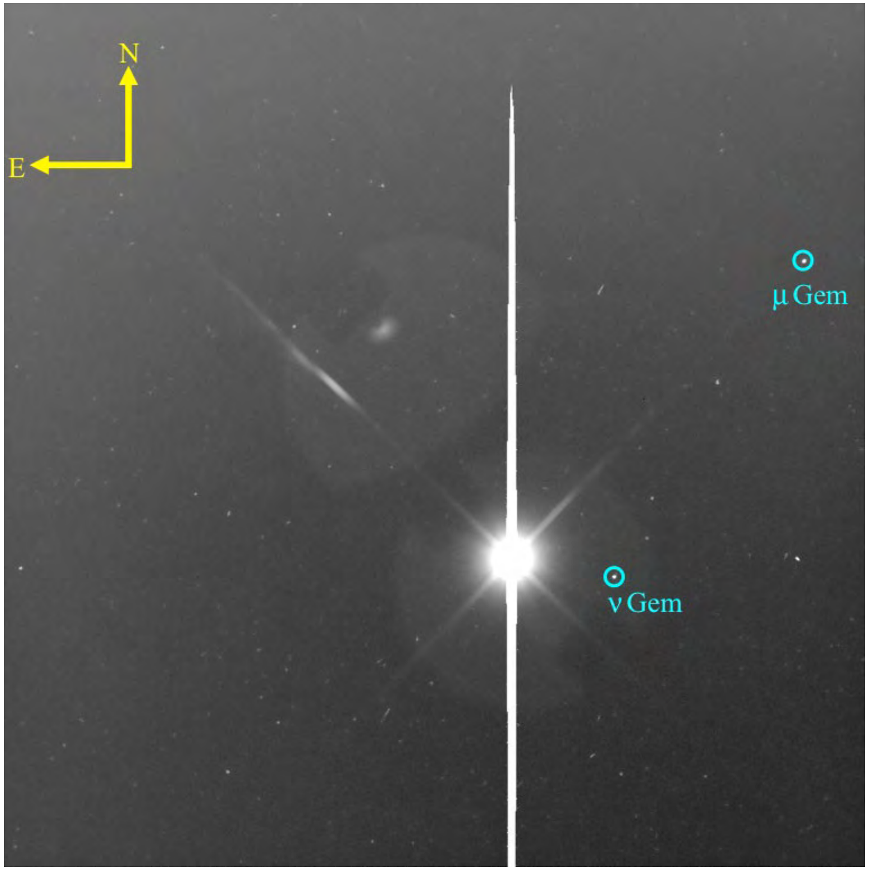
- ONC-T（telescopic）and ONC-W1（wide-angle）are being used to image Ryugu.
- Goals:
  - ➢ Optical navigation
  - ➢ Satellite search
  - ➢ Scientific observations（asteroid light curve）
- At the current time, the size of Ryugu is about 10 pixels on the ONC-T.

■Thermal Infrared Imager（TIR）

- Test observation and scientific observation（light curve）

2. Observation of Ryugu

Image of Ryugu taken with the ONC-T (Optical Navigation Camera – Telescopic)



The distance between Ryugu and the spacecraft is about 920km.

Ryugu's brightness is about -6.6 magnitude.

Image of Ryugu taken with the ONC-T on June 13, 2018 at approximately 13:50 JST. Field of view is 6.3 degrees x 6.3 degrees and the exposure time is about 178 seconds.

Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University.

ONC team：JAXA, University of Tokyo, Koichi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu and AIST.

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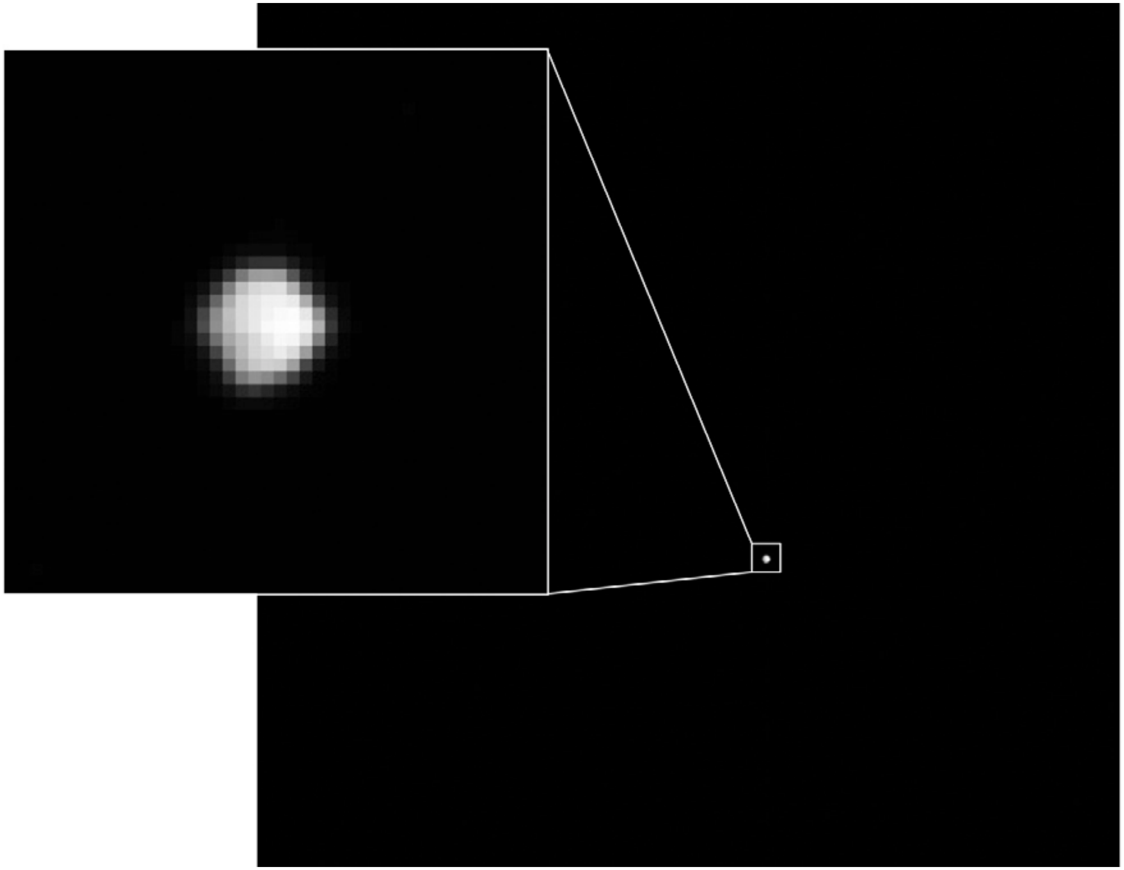

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Ryugu's brightness is about -6.6 magnitude.

Image of Ryugu taken with the ONC-T on June 13, 2018 at approximately 13:50 JST. Field of view is 6.3 degrees x 6.3 degrees and the exposure time is about 0.09 seconds.

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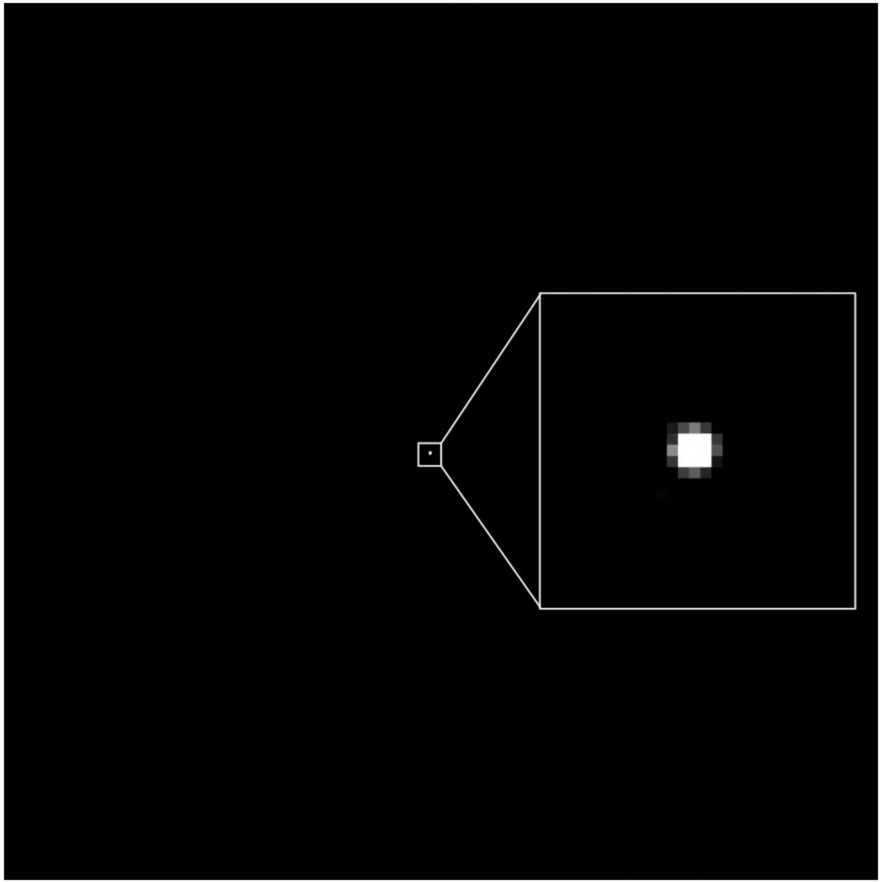
ONC team：JAXA, University of Tokyo, Koichi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu and AIST.

2. Observation of Ryugu

Image of Ryugu taken with the ONC-W1 (Optical Navigation Camera – Wide-angle)



The distance between Ryugu and the spacecraft is about 920km.

As the measurement of the asteroid position is more accurate when Ryugu is photographed by ONC-T, the ONC-T data is used for optical navigation. Imaging by ONC-W1 is a backup in case imaging with ONC-T failed.

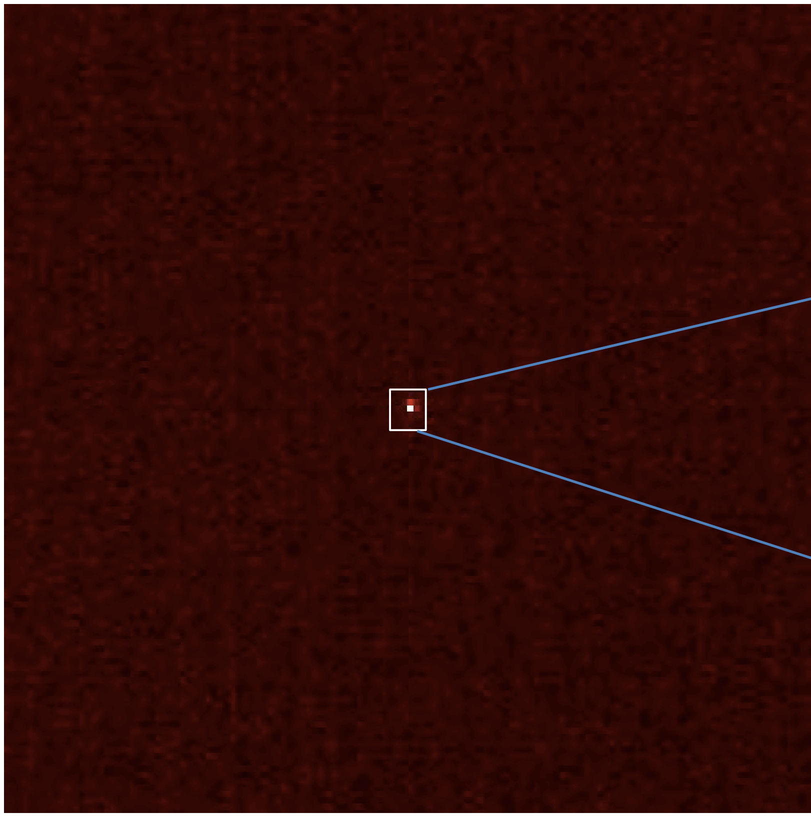
Image of Ryugu taken with the ONC-W1 on June 13, 2018 at approximately 13:00 JST. Field of view is 65 degrees x 65 degrees and the exposure time is about 0.2 seconds.

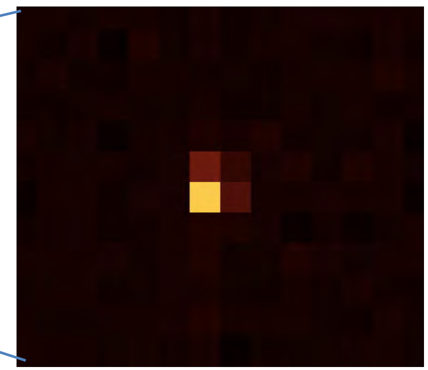
Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University.

ONC team：JAXA, University of Tokyo, Koichi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu and AIST.

2. Observation of Ryugu

Image of Ryugu taken with the TIR（Thermal Infrared Imager）





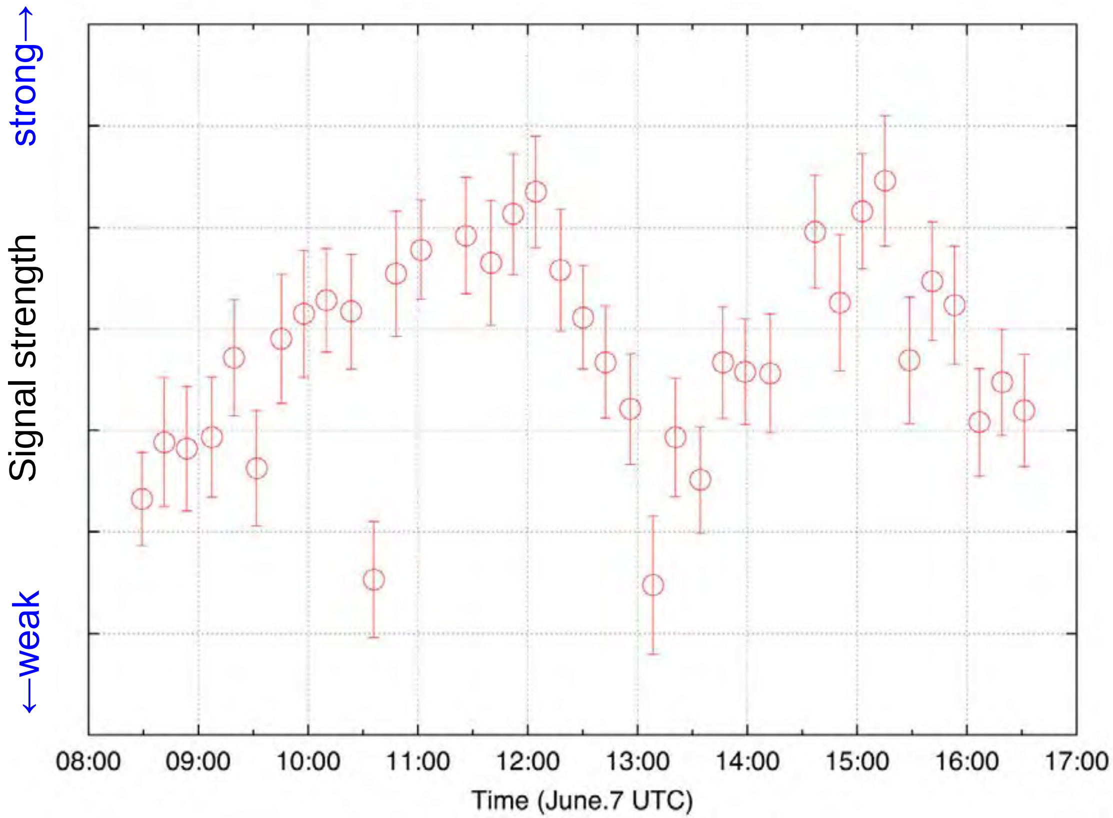
The distance between Ryugu and the spacecraft is 2100 km.

Image of Ryugu taken with the TIR on June 7, 2018 at approximately 18:45 JST. Field of view on the left image is 6 degrees x 6 degrees and the right image is a magnification. The exposure time is about 0.5 seconds.

TIR team：JAXA, Hokkaido University of Education, Rikkyo University, University of Aizu, Chiba Institute of Technology, Ashikaga University, AIST, National Institute for Environmental Studies, Hokkaido Kitami Hokuto High School, University of Tokyo, Max Planck Institute, DLR, Stirling University.

2. Observation of Ryugu

Light curve of Ryugu from the TIR (Thermal Infrared Imager)



※The absolute value of the signal strength will be analyzed in the future.

This light curve confirms the asteroid's rotation is about 7.6 hours, as expected.

Light curve of Ryugu obtained with the TIR (change in intensity of the signal). Data is from 37 images taken between June 7, 2018 at about 17:30 JST to June 8 at about 01:30 JST. Exposure time for each image was 0.5 seconds.

TIR team：JAXA, Hokkaido University of Education, Rikkyo University, University of Aizu, Chiba Institute of Technology, Ashikaga University, AIST, National Institute for Environmental Studies, Hokkaido Kitami Hokuto High School, University of Tokyo, Max Planck Institute, DLR, Stirling University.

2. Observations of Ryugu

■LIDAR（laser altimeter）

・On June 6, power was turned on and confirmed that the system starts up normally. It has been two years since the power was last turned on.

・Distance measurement to the asteroid will be attempted once Ryugu is sufficiently close (measurement range is 25km – 30m)

■NIRS3（Near Infrared Spectrometer）

・On June 6, the power was turned on and normal start up confirmed. It has been about half a year since the power was last turned on.

・ Observations of Ryugu will be attempted during the approach in the future.

3. Optical Navigation

Reasons for Optical Navigation (hybrid navigation using optical and radiometric measurements):

- Necessary technique to arrive at a celestial body 900m in size at a distance 300 million km from Earth.
- The errors (uncertainties) for the orbit of spacecraft and asteroid:

	Error in the position estimation
Hayabusa2 （At a distance of about 300 million km）	About 300km（Using the conventional RARR） Several km（by DDOR）
Asteroid Ryugu	About 220km（as of May 2018)

Note）･RARR is the abbreviation of “Range and Range Rate”, a conventional method to estimate the trajectory of a spacecraft by measuring the distance to the probe and velocity along the line of sight using radiowave communication.
･DDOR is “Delta Differential One-way Range”, a method of accurately estimating the trajectory by receiving radiowaves from the probe at two ground stations simultaneously.
･ The size of the error is 3σ (probability of 99.7%)

- Using Optical Navigation during the approach to the asteroid reduces these errors.

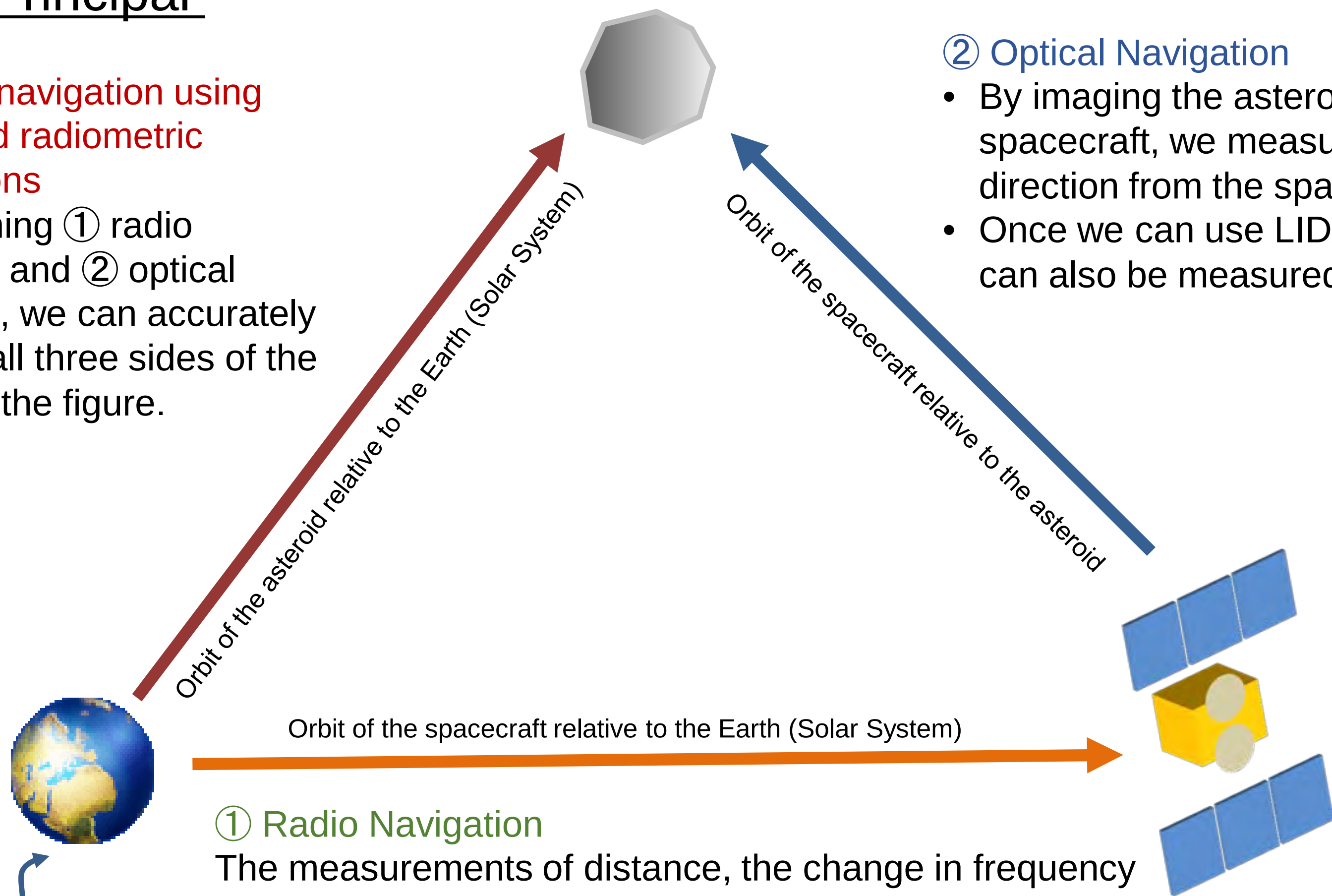
Reference：
A 900m target at a distance of 300 million km is equivalent to a 6cm target at 20,000 km. In other words, arriving at Ryugu is the same as aiming at a 6cm target in Brazil from Japan!

3. Optical Navigation

Basic Principal

③ Hybrid navigation using optical and radiometric observations

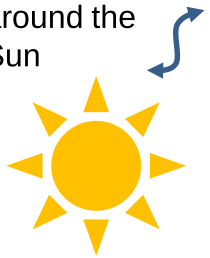
By combining ① radio navigation and ② optical navigation, we can accurately calculate all three sides of the triangle in the figure.



② Optical Navigation

- By imaging the asteroid from the spacecraft, we measure the asteroid's direction from the spacecraft.
- Once we can use LIDAR, the distance can also be measured.

Earth's orbit around the Sun

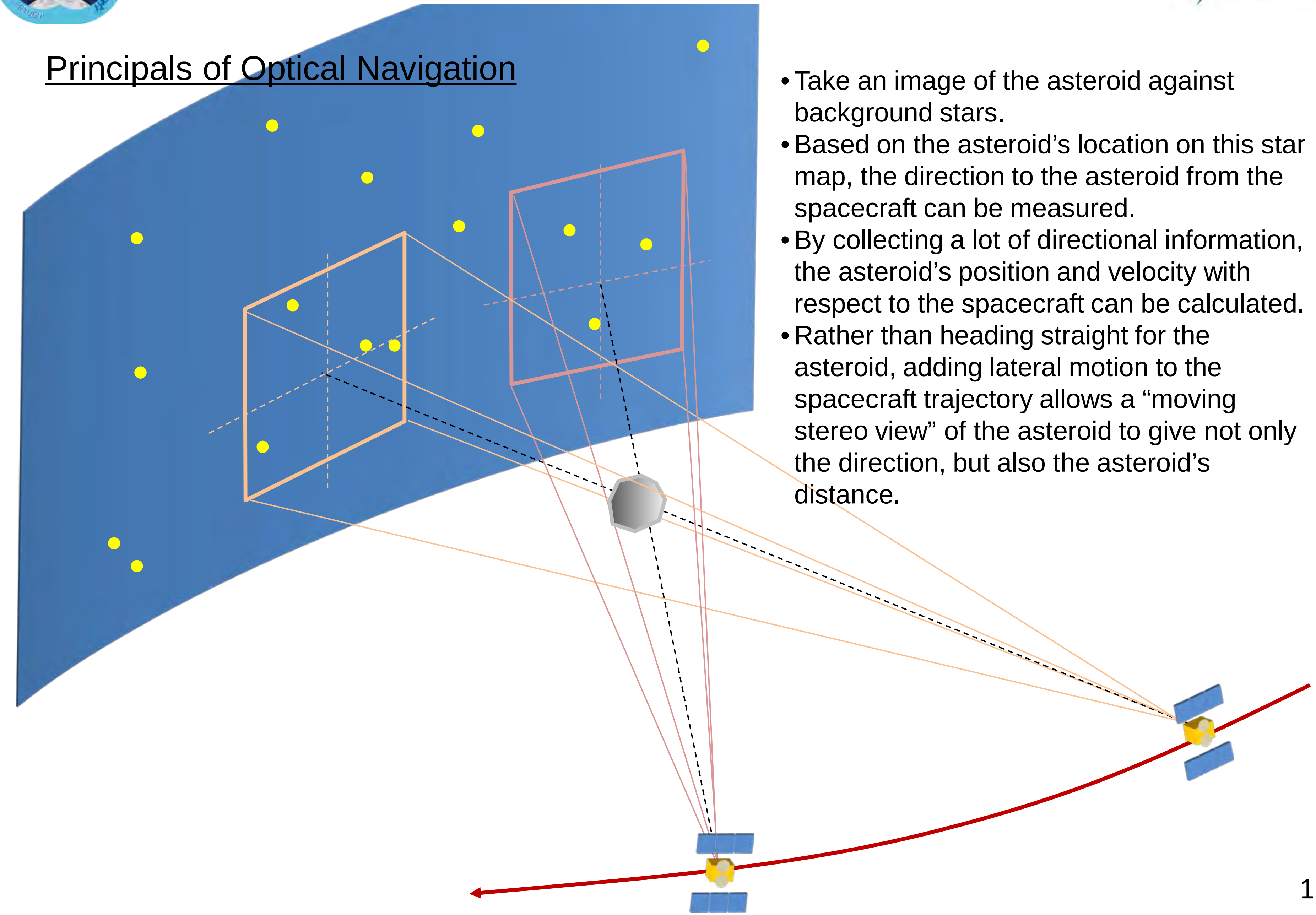


① Radio Navigation

The measurements of distance, the change in frequency from transmitted & received radiowaves between the Earth and spacecraft (Doppler effect), and DDOR gives the trajectory of the spacecraft relative to the Earth.

Note: It is common to refer to "hybrid navigation using optical and radiometric observations" as simply "Optical Navigation".

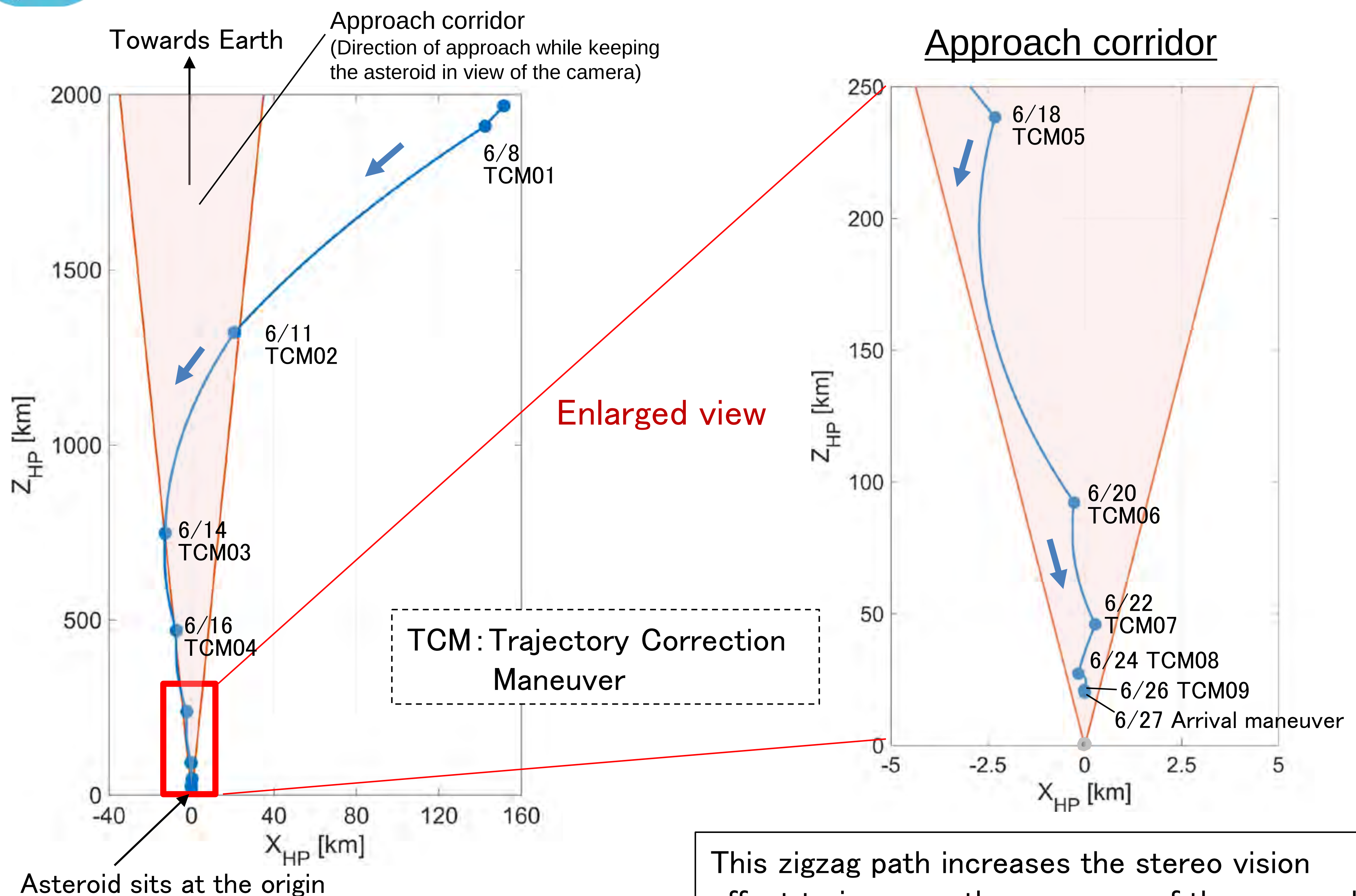
3. Optical Navigation



Principals of Optical Navigation

- Take an image of the asteroid against background stars.
- Based on the asteroid's location on this star map, the direction to the asteroid from the spacecraft can be measured.
- By collecting a lot of directional information, the asteroid's position and velocity with respect to the spacecraft can be calculated.
- Rather than heading straight for the asteroid, adding lateral motion to the spacecraft trajectory allows a "moving stereo view" of the asteroid to give not only the direction, but also the asteroid's distance.

3. Optical Navigation



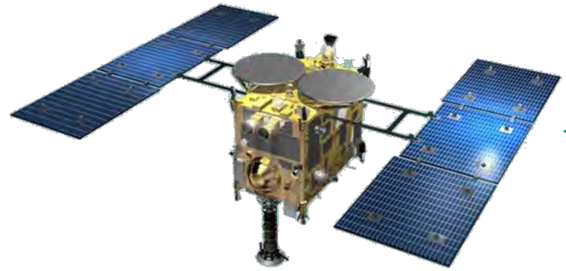
TCM: Trajectory Correction Maneuver

This zigzag path increases the stereo vision effect to increase the accuracy of the approach

※The trajectory may be changed in future operations.

3. Optical Navigation

Work loop



Received from Hayabusa2:
- Thruster injection history
- Asteroid image

Sent to Hayabusa2:
- Thruster injection plan
- Asteroid image plan

Perform this loop once every 24 – 72 hours

Seoul National University

Japan Spaceguard Association

Kyoto University

JAXA

→ Navigation team: JAXA, NEC, Fujitsu

→ Guidance team: JAXA

→ Operation team: JAXA, NEC

Calculate the direction to the asteroid from Hayabusa2 using the image of stars and asteroid.

Calculate the trajectory of Hayabusa2 towards Ryugu based on the asteroid direction and radio wave measurements.

Calculate the optimal trajectory to arrive at the asteroid based on the latest Hayabusa2 orbit.

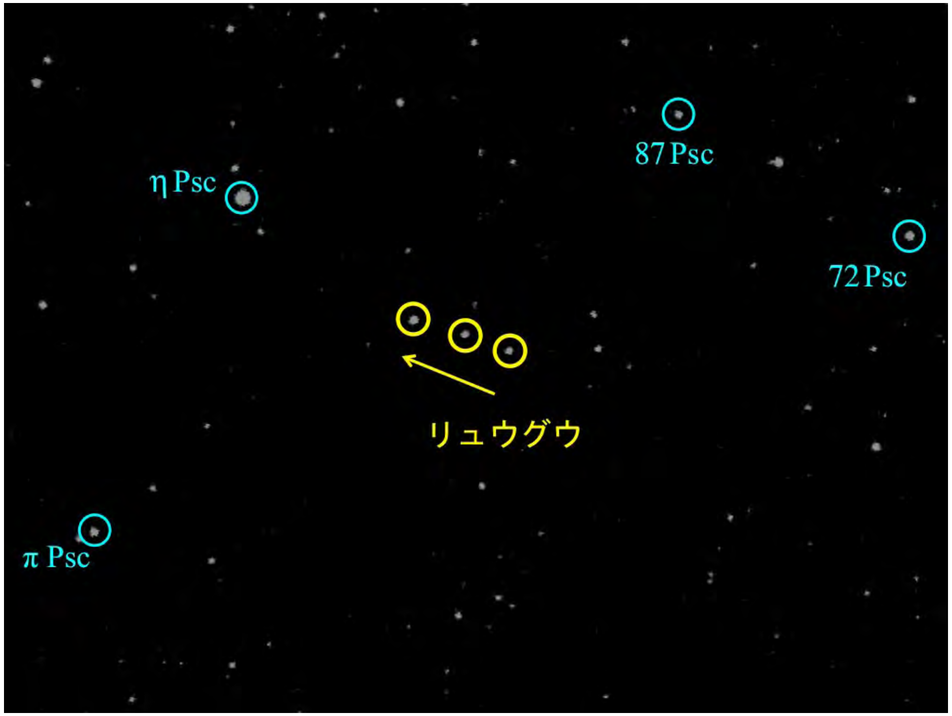
From the latest trajectory plan, send new thruster injection commands and image plan to the spacecraft.

3. Optical Navigation

Optical Navigation performed using images from the STT（Star Tracker)

- Ion engine operation was in progress during May, preventing the Optical Navigation Camera pointing at Ryugu. Instead, an image of Ryugu was attempted with the Star Tracker, which is usually used to determine the orientation of the spacecraft.

- Ryugu was observed between May 11 – 14 and Optical Navigation was used from measurements of the asteroid's position.
- As a result, the error (uncertainty) in the position of the asteroid shrank from 220km to about 130km.
- Based on the trajectory estimate obtained form this Optical Navigation, the final ion engine operation was performed.

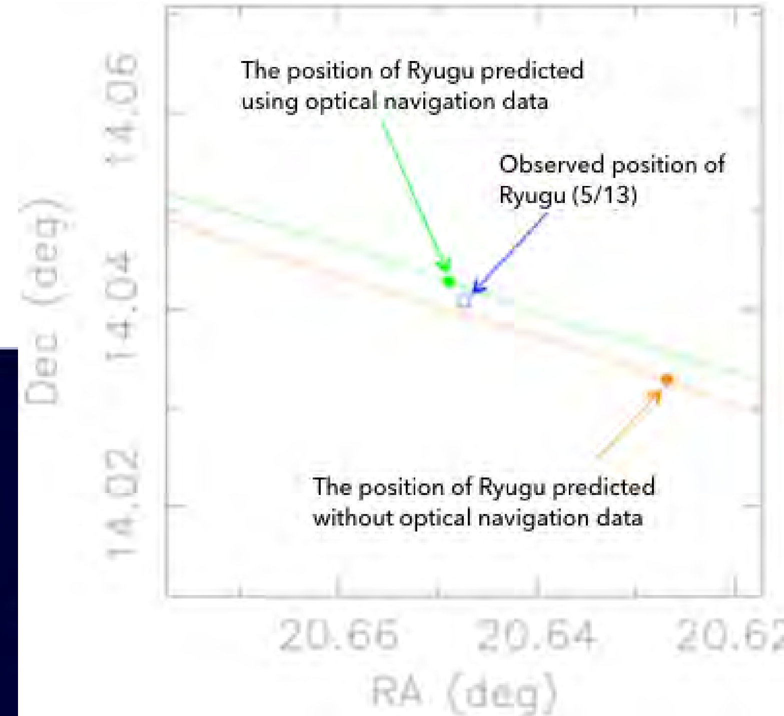


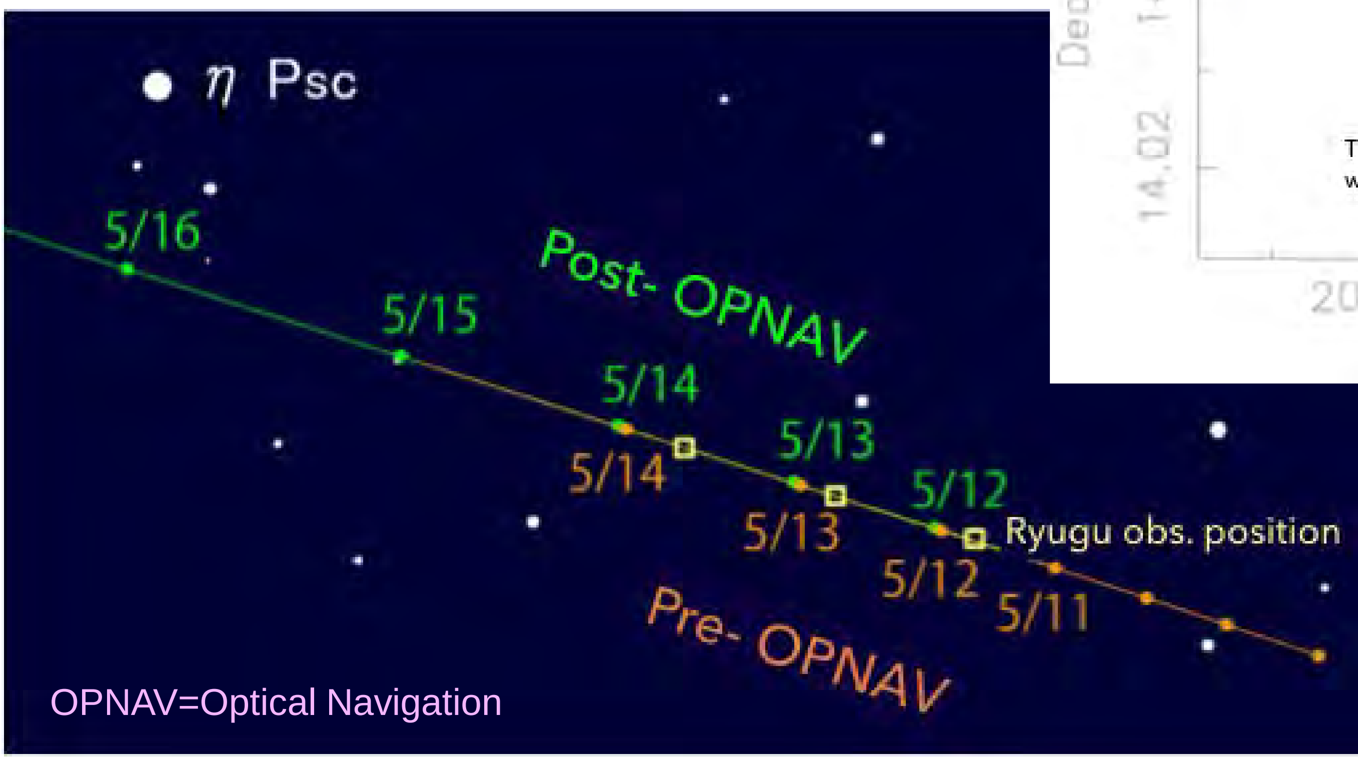
Ryugu photographed with the Star Tracker. The images were taken starting from the right at approximately 01:00 on May 12, 02:00 on May 13 and 01:00 on May 14 (JST). These are taken from the spacecraft in the direction of Pisces. ("Psc" is an abbreviation of Pisces). The field of view is 9 degrees × 7 degrees. (Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University.)

3. Optical Navigation

<u>Optical Navigation performed using images from the STT（Star Tracker)</u>

Orange: Expected position of Ryugu seen from the spacecraft calculated from orbital information prior to using optical navigation.
Green: Expected position of Ryugu calculated with greater accuracy using optical navigation data.
Yellow: The direction of the observed Ryugu.



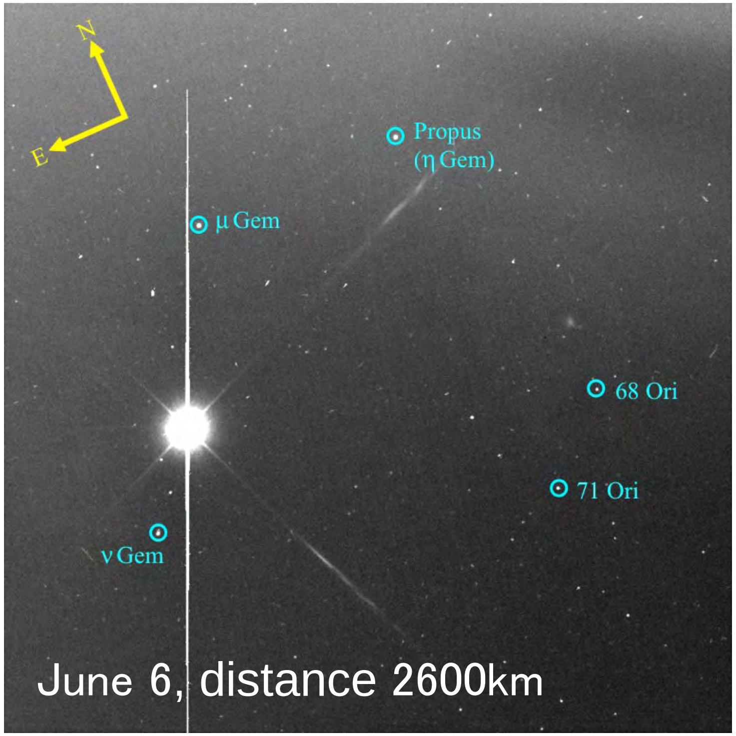


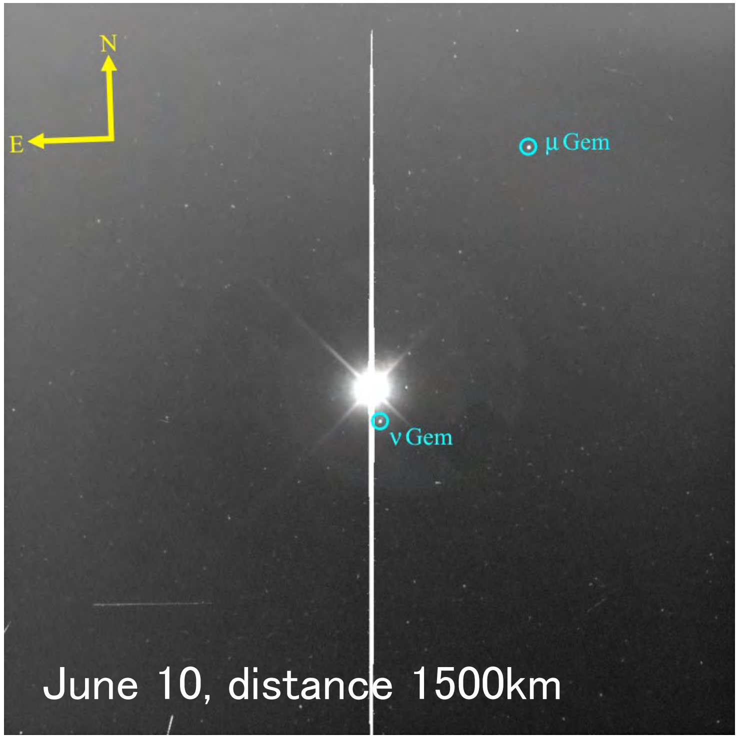
Enlarged section around the 5/13 observation of Ryugu.

3. Optical Navigation

Optical Navigation performed using imaged from the ONC (Optical Navigation Camera)

Examples of images with the ONC-T





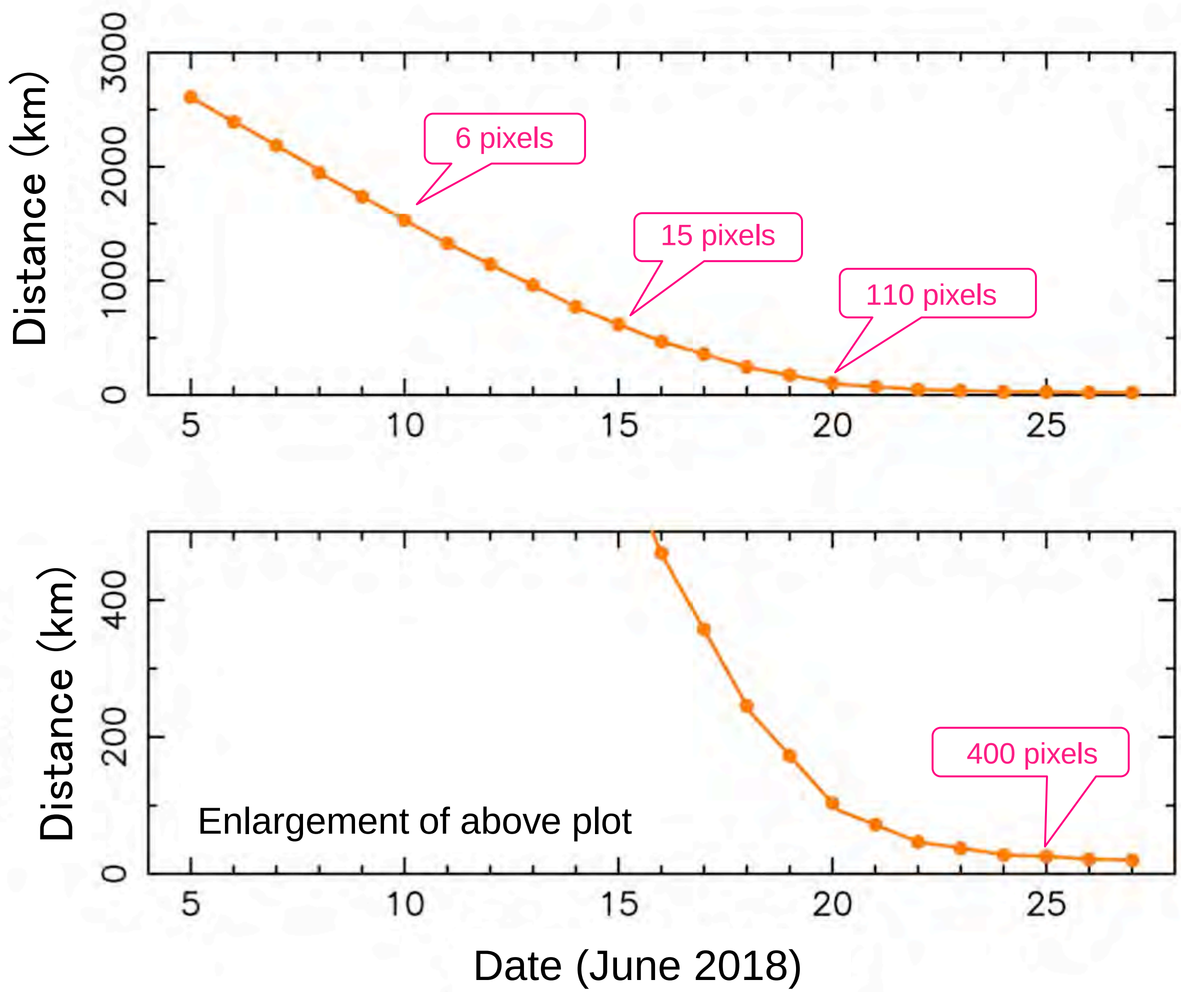
TCM：Trajectory Correction Maneuver

TCM	Time（JST）	x-direction velocity	y-direction velocity	z-direction velocity
TCM01	June 8, 2018 12:30～13:40	-24 cm/s	-5 cm/s	14 cm/s
TCM02	June 11, 2018 09:30～10:40	13 cm/s	-1 cm/s	26 cm/s

※ This is in the home position coordinate system (where the z-axis is in the direction of the Earth from the asteroid).

3. Optical Navigation

Change in distance between Ryugu and the spacecraft

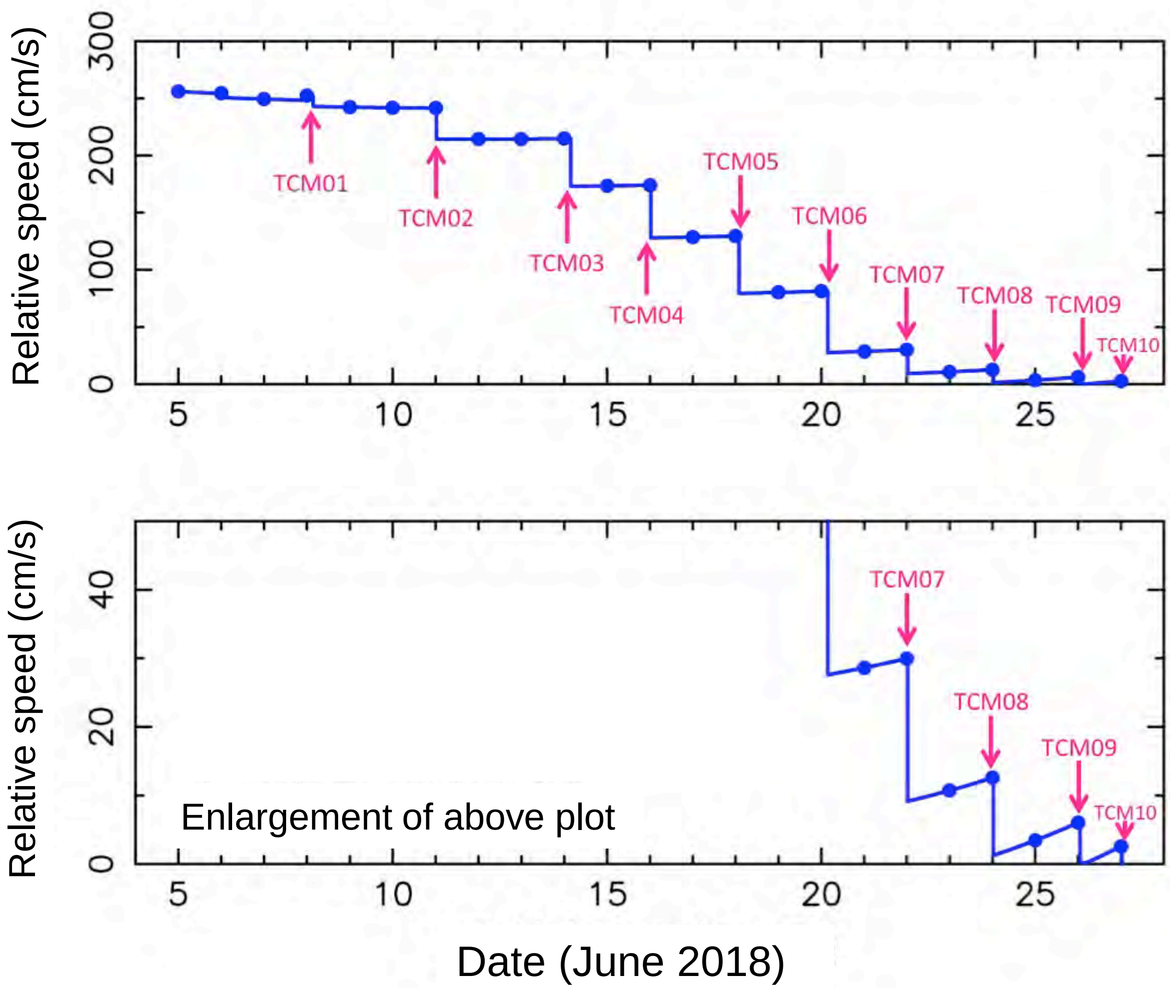


Predicted values at the present time.

The number of pixels indicates the expected diameter of Ryugu when photographed with the ONC-T.

3. Optical Navigation

Change in the relative speed between Ryugu and the spacecraft and the TCM



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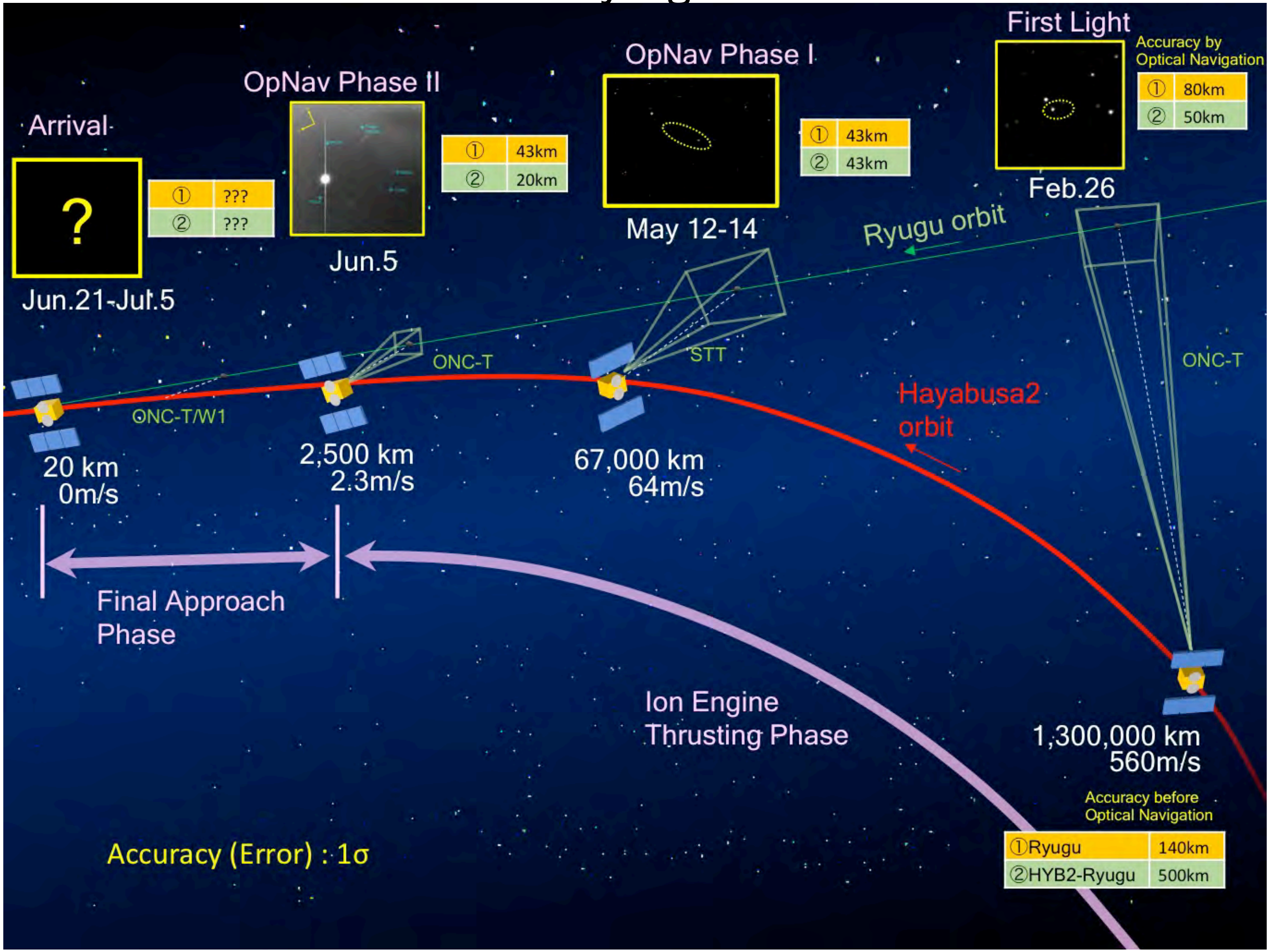
TCM：Trajectory Correction Maneuver

3. Optical Navigation

Summary figure

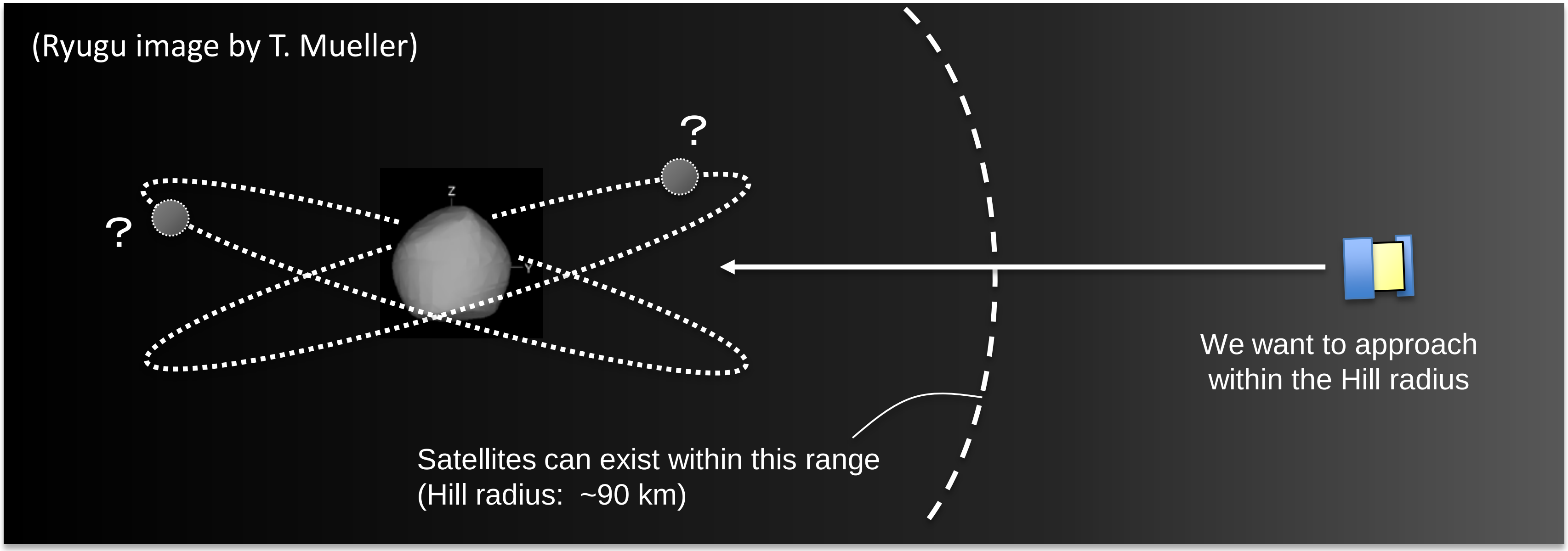


4. Search for satellites

celestial bodies that may orbit Ryugu

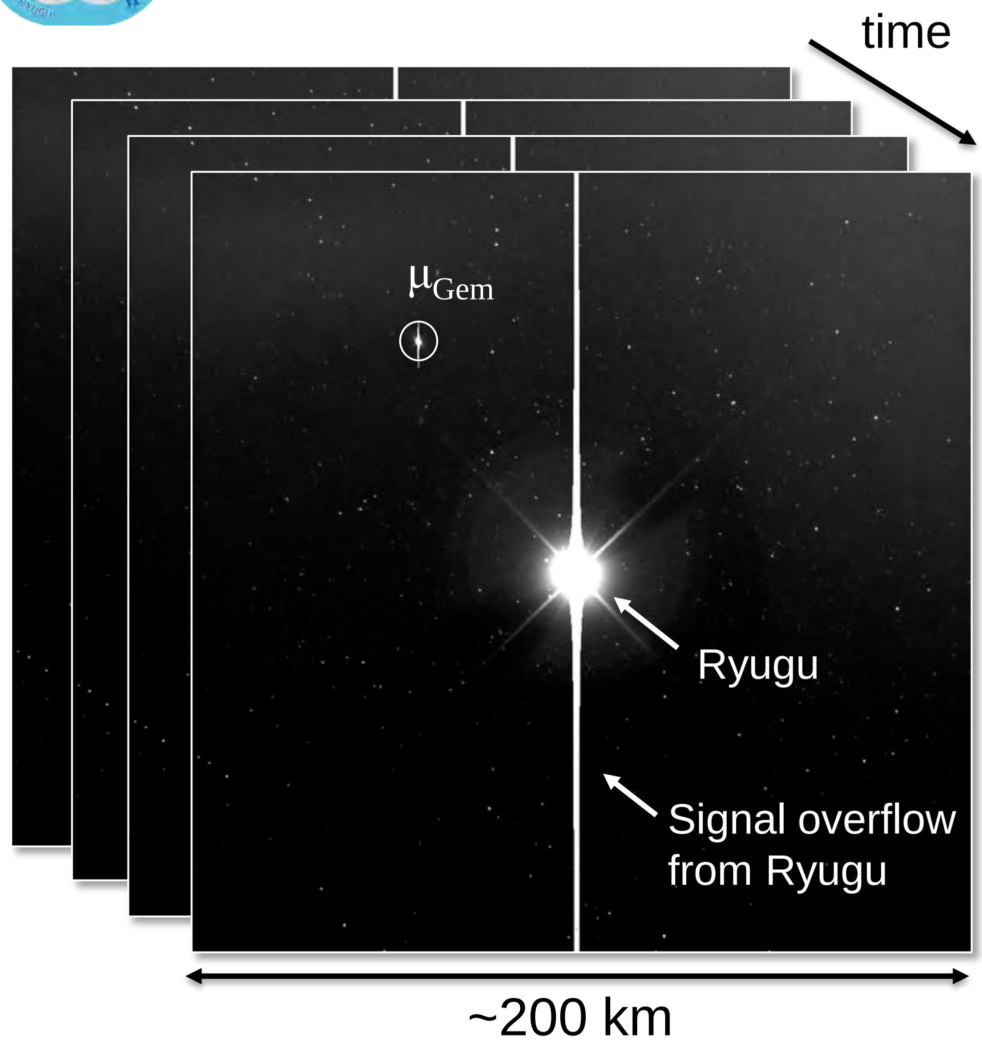
Reasons for a satellite search

- Even the low gravity Ryugu can also have satellite



- No matter how small, a collision with a satellite is fatal to the mission. However, if if there are satellites around Ryugu then it would be <u>scientifically a great discovery</u>.
- Ryugu was searched for orbiting objects from a safe distance (on June 7 at 2,100km). From here, satellites smaller than 1m in diameter could be discovered. Such observations were also performed for Hayabusa [Fuse et al, 2008]

4. Search for satellites



Satellite search observation record (June 7)

① 08:03 – 08:09
② 11:06 – 11:12
③ 14:17 – 14:23
④ 16:35 – 16:41

*multiple occasions to capture orbital movement.

A small satellite emits only a small amount of light. To capture this, a 178 second exposure it used for observations (30,000 times longer than the normal setting).

* Dim stars above magnitude 12 can be seen.

No satellites larger than the detection limit (50cm) were seen.

It is safe to approach the stable orbit radius for a satellite smaller than 50cm (up to 50km). As we approach Ryugu, we will continue to search for smaller satellites.

ONC team：JAXA, University of Tokyo, Koichi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu and AIST.

Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University.

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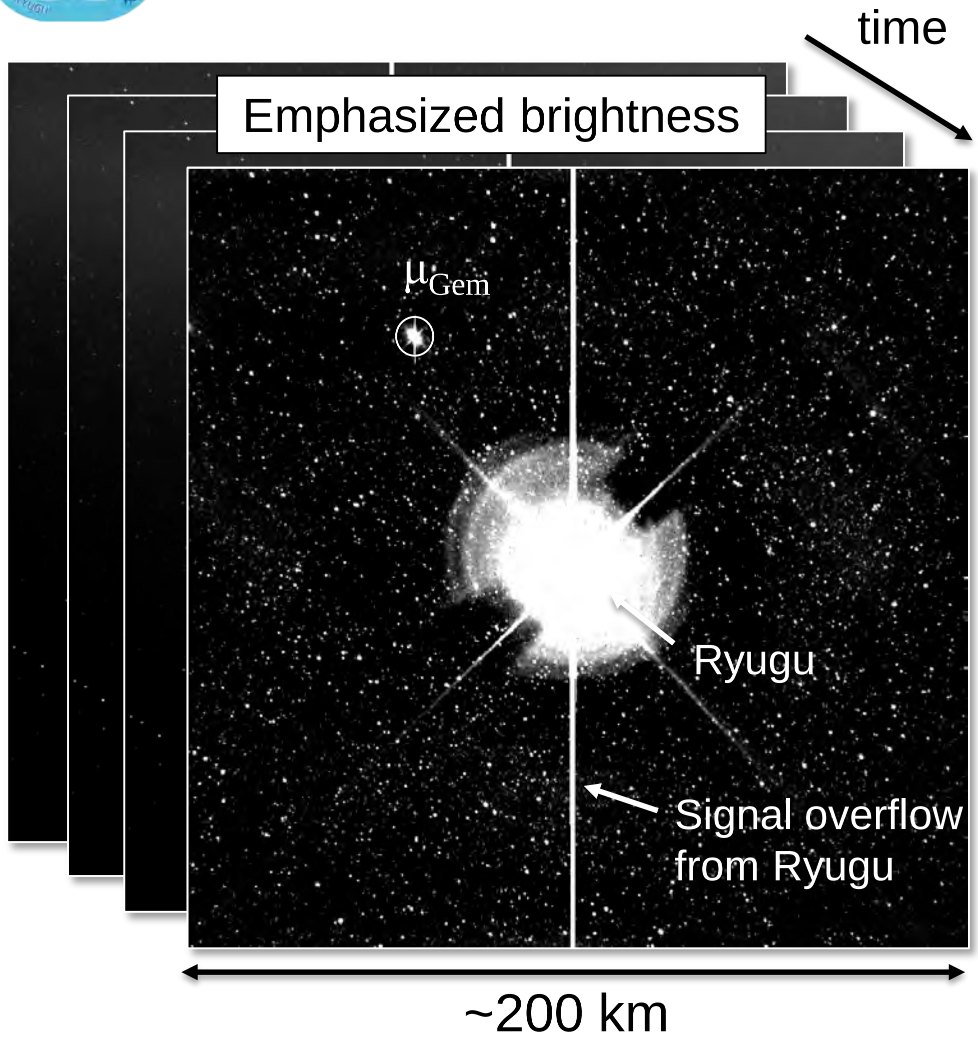

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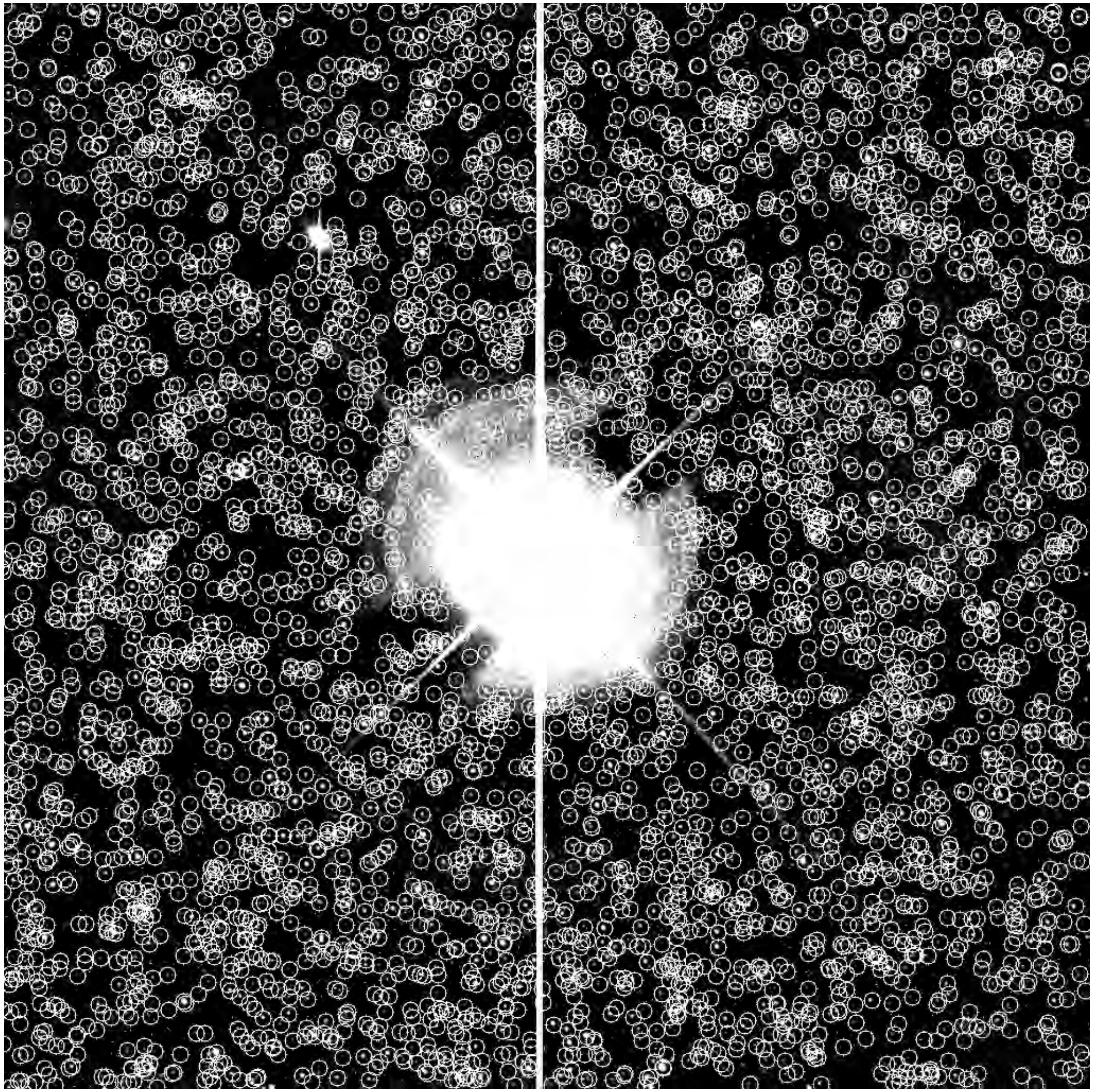
4. Search for satellites

Reference:
Stars brighter than 12 magnitudes are marked with a circle.



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Ground observation team: JAXA, Kyoto University, Japan Spaceguard Association, Seoul National University.

5. Mission Schedule

Recent Operations

- Continue Optical Navigation
- Continue satellite search
- Continue scientific observation

- Arrival at Ryugu is scheduled for around June 27 (exact date may vary by a few days, depending on the exact operation situation).

Operation in the asteroid vicinity

- The specific schedule will be determined based on observations between June and August
- The current schedule is on the next page.

5. Mission schedule

Provisional version

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)	Planning
	End of July	Medium altitude observations #1 (alt. 5km)	Planning
	August	Decent to measure gravity (alt.1km)	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’.

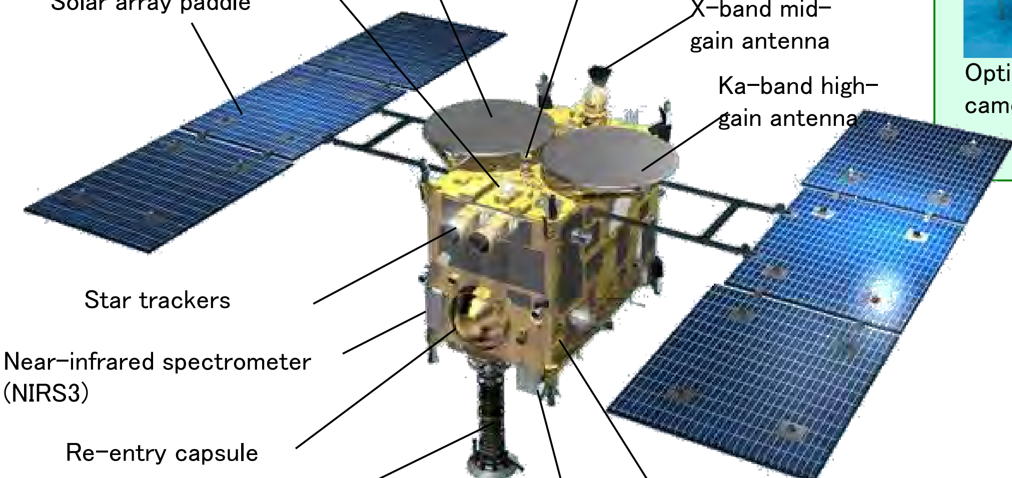
6. Future plans

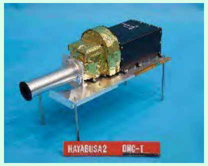
Media correspondence & information disclosure:

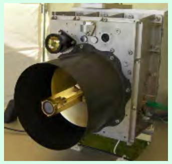
- Arrival at 20km above Ryugu is scheduled for around June 27. At this time, a press release will be posted and press briefing (@ the Sagamihara campus) will be scheduled.
- We plan to hold regular press briefings after July. (In the next two months, July 19, August 2, August 23 are planned.)

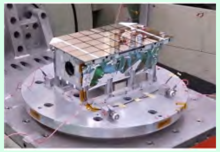
Reference material

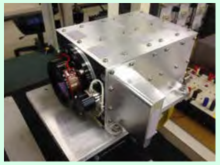
Primary spacecraft components




Optical navigation camera, ONC-T


Laser altimeter, LIDAR


Near-infrared spectrometer, NIRS3


Thermal infrared camera, TIR

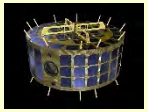
Scientific observation equipment

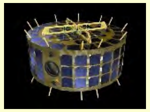
Small lander & rovers

MASCOT

Built by DLR and CNES

Minerva 2


II-1A


II-1B


II-2

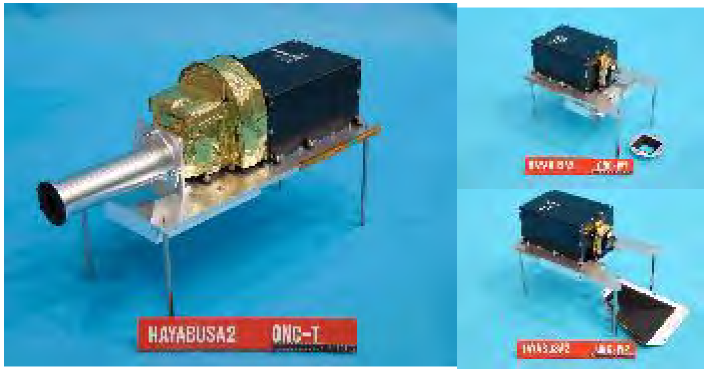
II-1: By the JAXA Minerva-II team

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

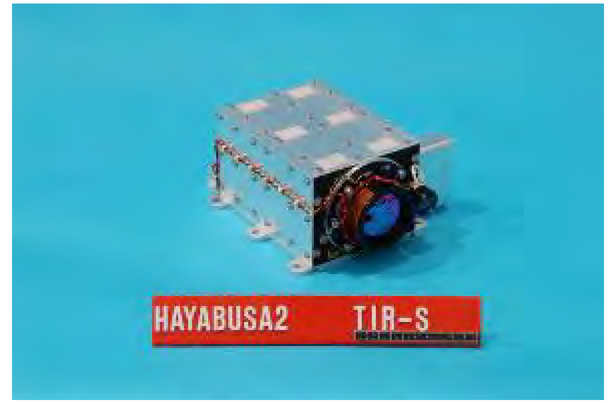
Optical Navigation Camera (ONC)



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

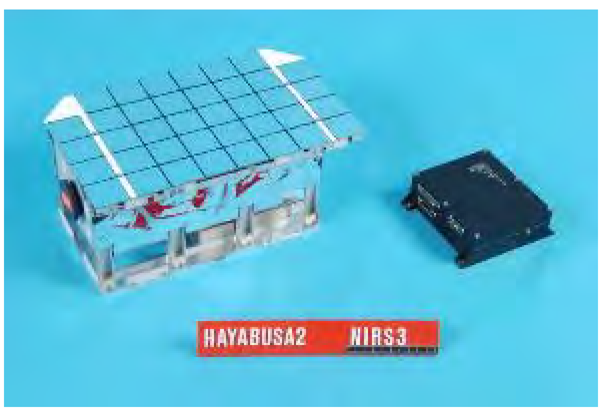
Imaging for scientific observation and navigation

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

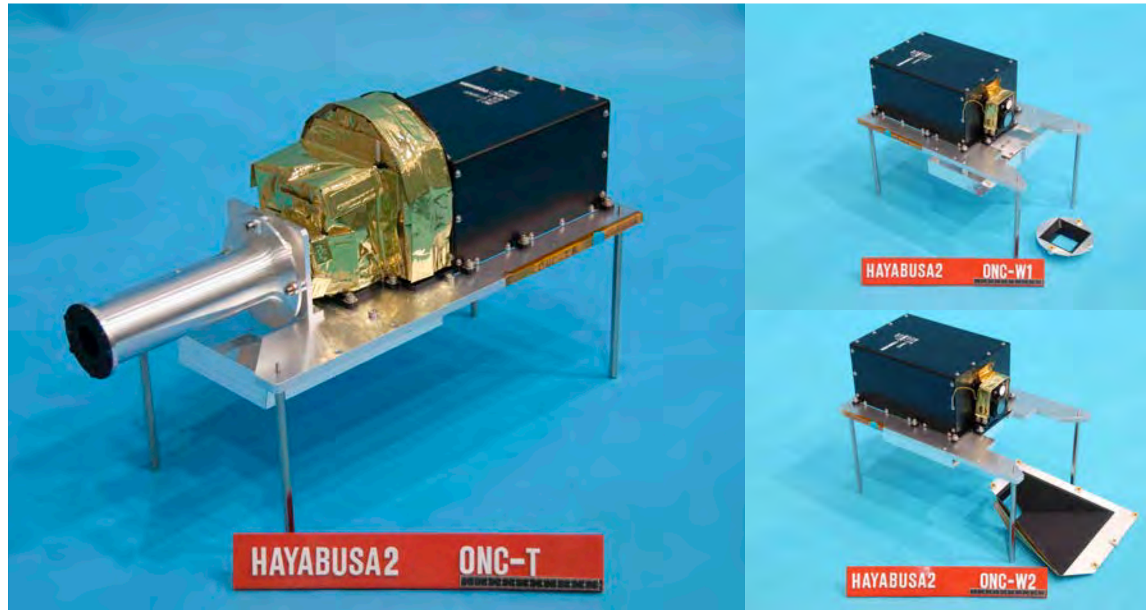
Optical Navigation Camera (ONC)

ONC: Optical Navigation Camera

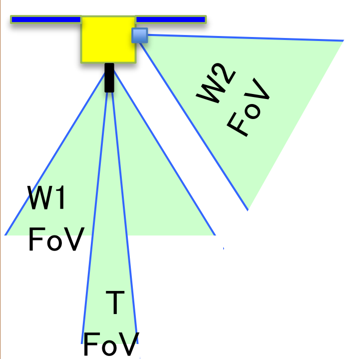
Objective: Images fixed stars and the target asteroid for spacecraft guidance and scientific measurements

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



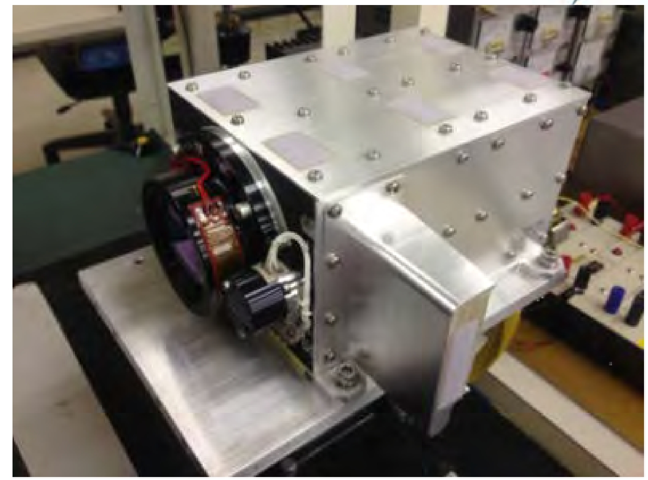
- Elucidation of features of target asteroid
  - Distribution of hydrous minerals and organic matter, space weathering, boulders
- Sampling site selection
  - Basic information on where to collect asteroid samples
- Ascertaining sample state
  - High−resolution imaging of sampling sites



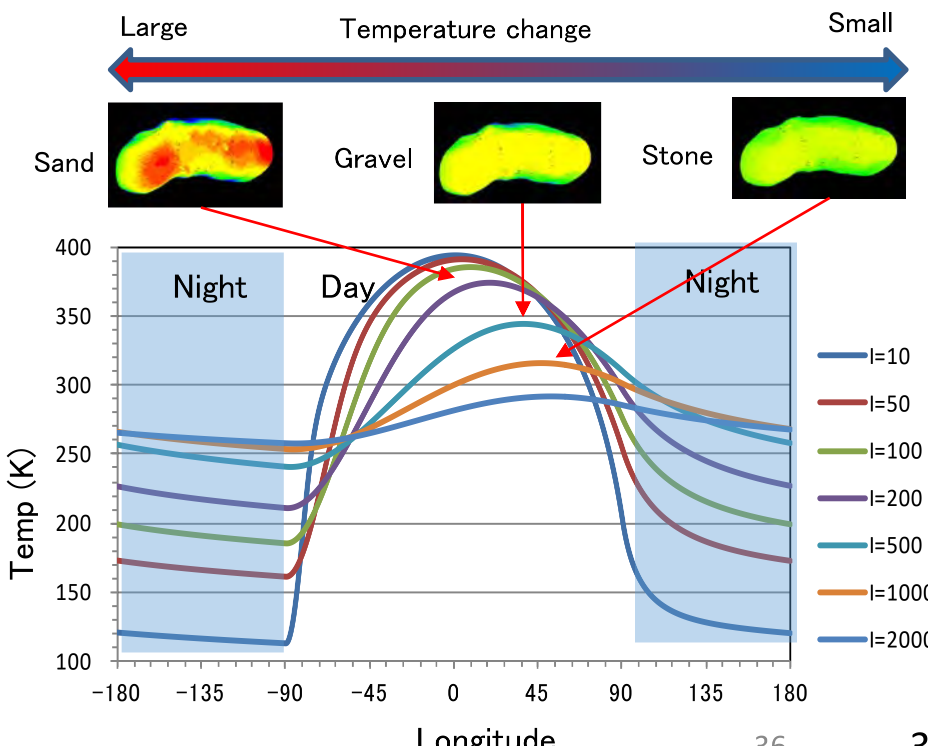
	ONC-T	ONC-W1	ONC-W2
Detector	2D Si-CCD (1024 × 1024 px)		
Viewing direction	Downward (telephoto)	Downward (wide-angle)	Sideward (wide-angle)
Viewing angle	6.35° × 6.35°	65.24° × 65.24°	
Focal length	100 m–∞	1 m–∞	
Spatial resolution	1 m/px @ 10-km alt. 1 cm/px @100-m alt.	10 m/px @10-km alt. 1 mm/px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

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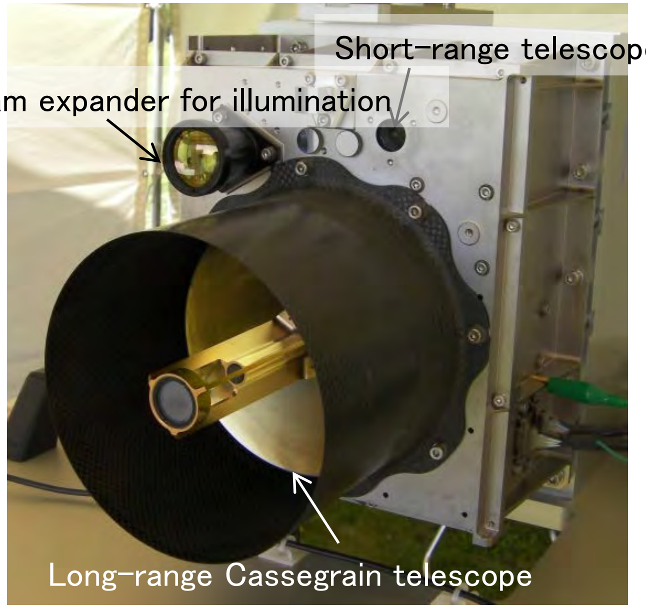
Laser altimeter (LIDAR)

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

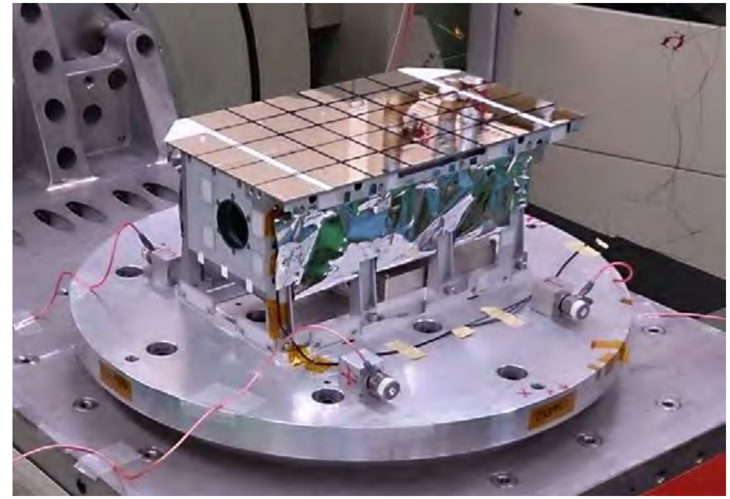
Scientific objectives
- Terrain and gravity field observations of the target asteroid
- Observations of albedo distribution at various surface points
- Observations of dust floating around the asteroid

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

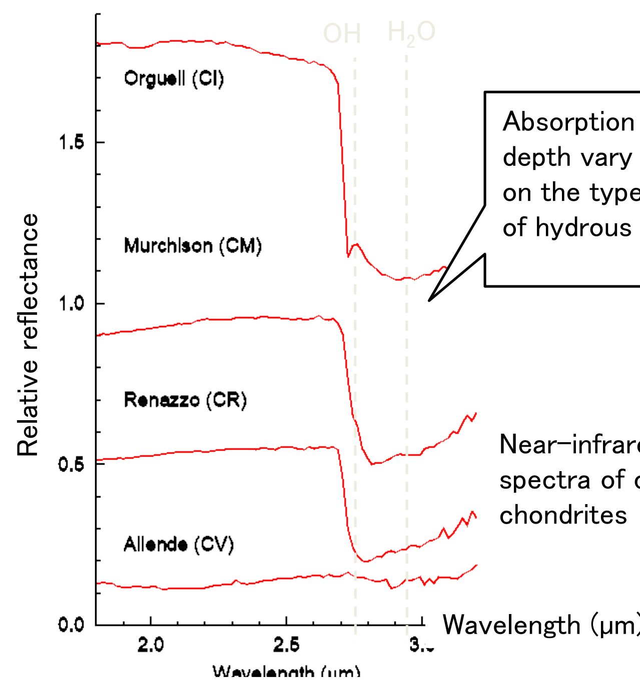
Near-infrared spectrometer (NIRS3)

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)



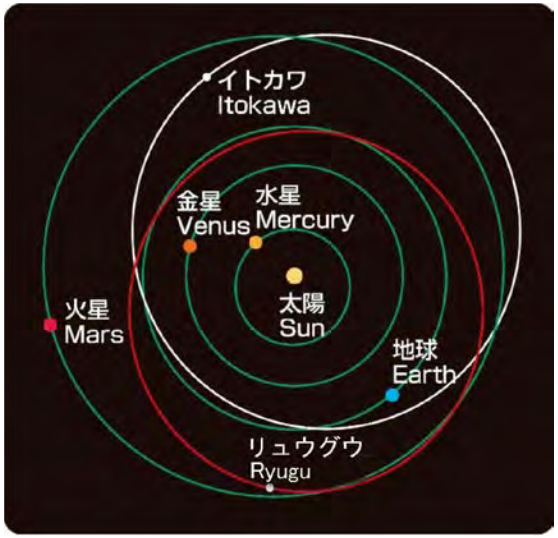
Absorption form and depth vary depending on the type and amount of hydrous mineral

Near-infrared reflection spectra of carbonaceous chondrites

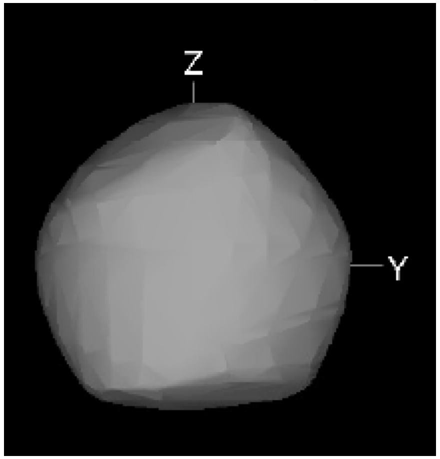
Asteroid Ryugu

Name	: Ryugu
Permanent designation	: 162173
Provisional designation	: 1999 JU_3
Discovered	: May 1999
Size	: Approx. 900 m
Shape	: Nearly spherical
Rotation period	: approx. 7 h 38 min
Rotation orientation	: Ecliptic longitude $\lambda = 310^\circ \; -340^\circ$ Ecliptic latitude $\beta = -40^\circ \; \pm -15^\circ$
Reflectivity	: 0.05 (blackish)
Type	: C type (assumed to comprise materials containing water and organics)
Orbital radius	: Approx. 180,000,000 km
Orbital period	: Approx. 1.3 yr
Density and mass	: Density is currently unknown, but presumed to be 0.5–4.0 g/cm^3 : Mass is approx. 1.7×10^{11} kg $- 1.4 \times 10^{12}$ kg.

Orbit of Ryugu

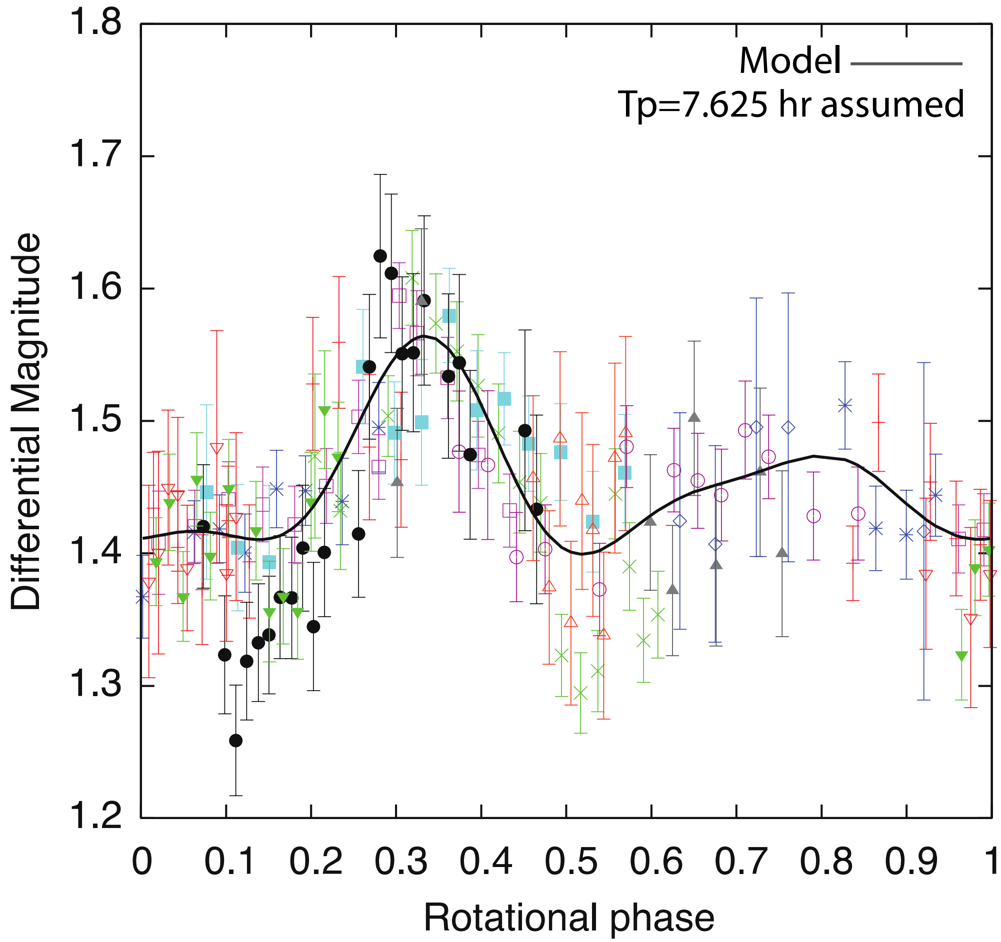


Estimated shape



(by T. Mueller)

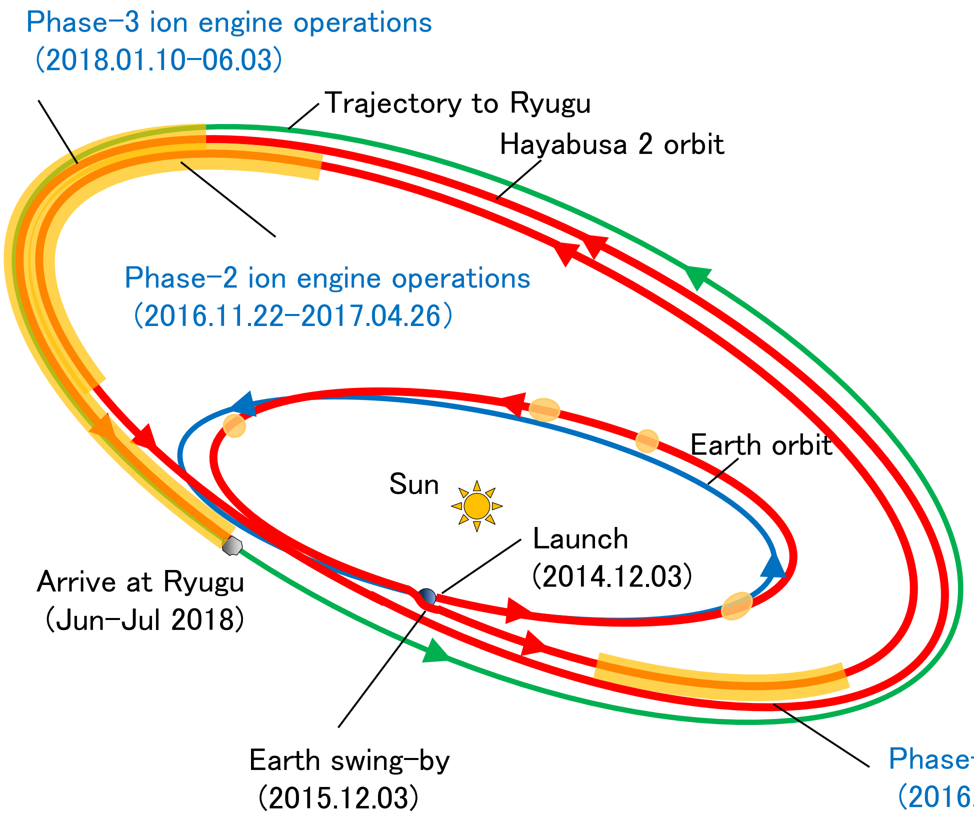
(162173) 1999 JU_3 (Ryugu) light curve



(from Kim, Choi, Moon et al. A&A 550, L11 (2013))

Ion engine operation

Summary of forward cruise ion engine operation



■Before swing-by

Period	Name	No. of thrusters	Δv m/s	Time h
Initial check	IES operations test	-	–	–
2015.03.03–21	IES Powered Navigation 1	2	44	409
2015.05.12–13	IES max. thrust test	3	4	24
2015.06.02–06	IES Powered Navigation 2	2	11	102
2015.09.01–2	IES Powered Navigation 3	2	1. 3	12

IES：ion engine system

■After swing-by

Period	Name	No. of thrusters	Δv m/s	Time
2016/3/22～2016/5/21	Phase 1: Ion engine operation	3（2 at times）	127	798 h
2016/11/22～ 2017/4/26	Phase 2: ion engine	3（2 at times）	435	2593
2018/1/10～2018/6/3	Phase 3: ion engine	2→3	393	2475