Asteroid explorer, Hayabusa2, reporter briefing

June 11, 2020

JAXA Hayabusa2 Project

Topics

Regarding Hayabusa2,

- Current trajectory plan
- Status of the second ion engine operation
- Recent scientific paper publications

Contents

0. Hayabusa2 and mission flow outline
1. Current status and overall schedule of the project
2. Current trajectory plan
3. Status of the 2nd ion engine operation
4. ONC photometric observations of Ryugu
5. Estimate of the thermophysical properties of Ryugu with the TIR
6. Future plans

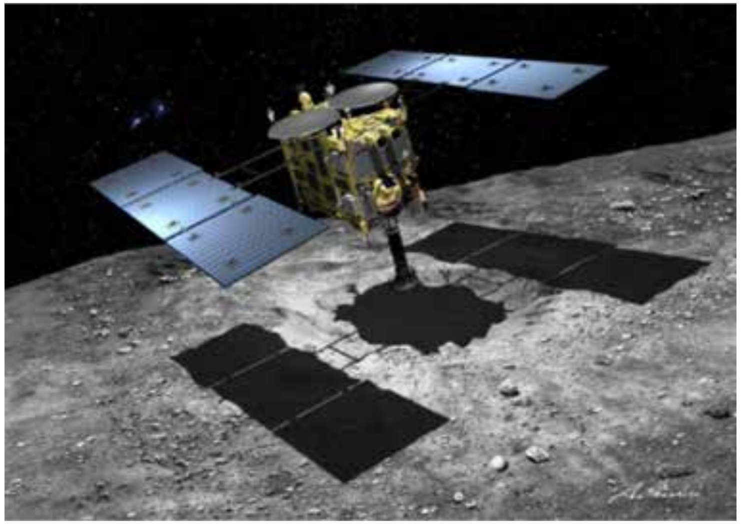
Overview of Hayabusa2

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.

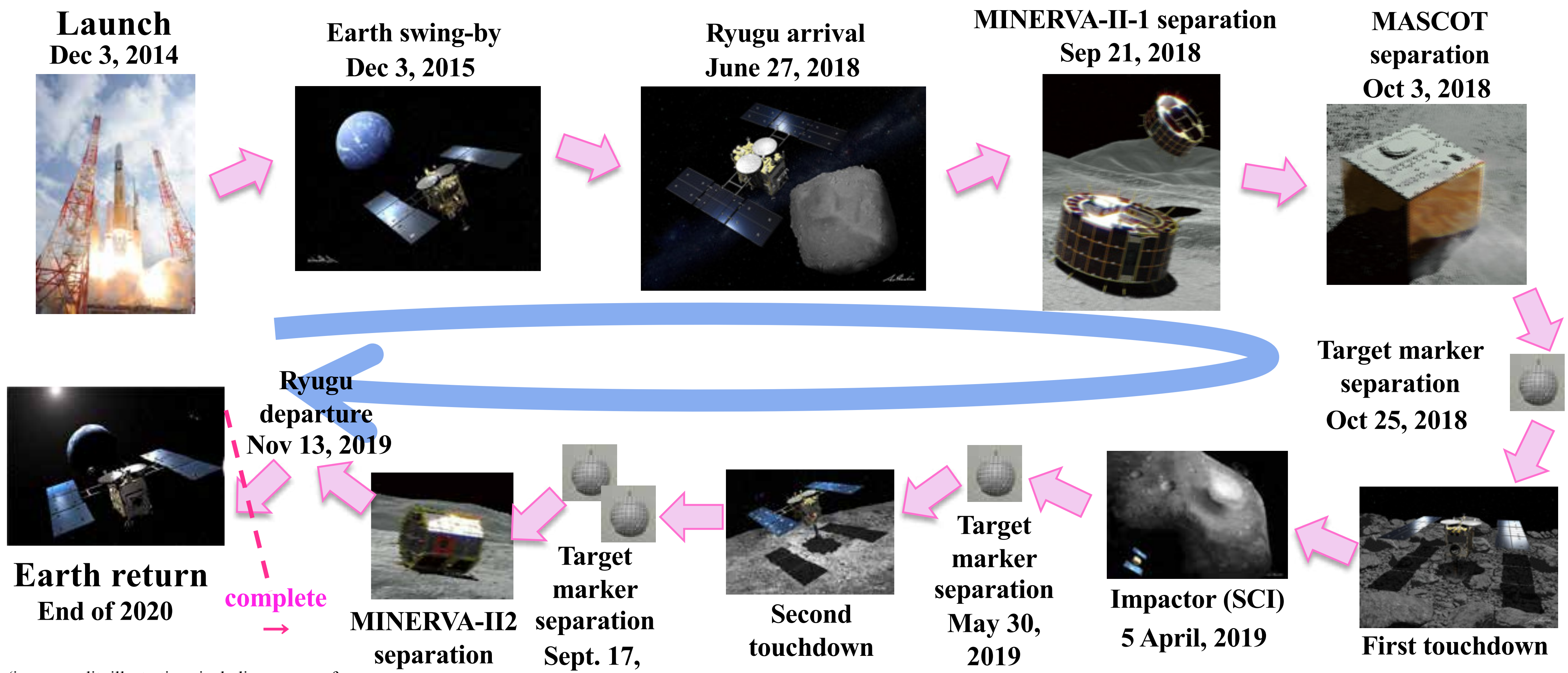

(Illustration: Akihiro Ikeshita)

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

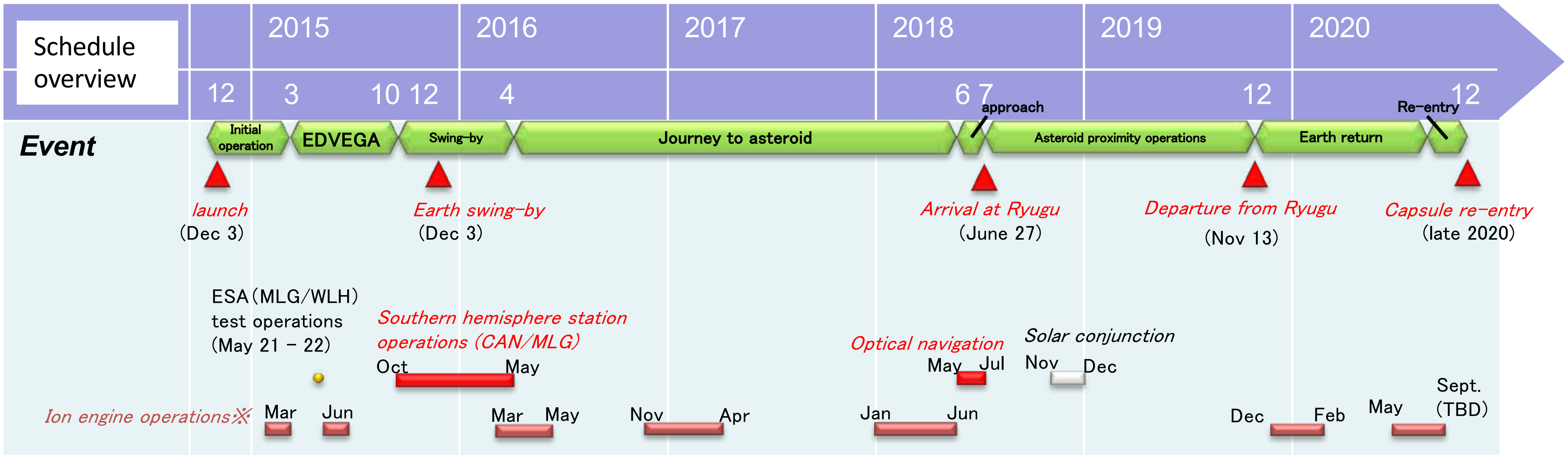


(image credit: illustrations including spacecraft by Akihiro Ikeshita, others by JAXA)

1. Current project status & schedule overview

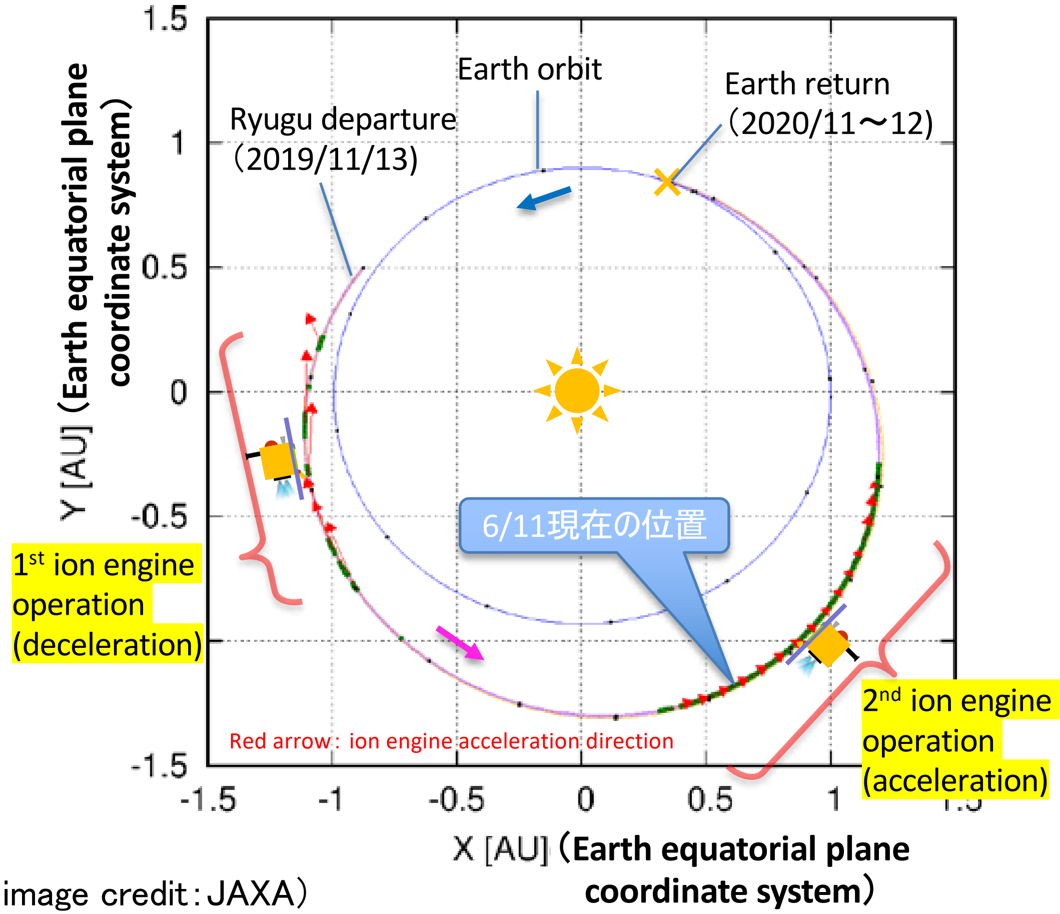
Current status:

- The 2nd ion engine operation began on May 12.
- Operations continue as planned, while precautions are in place to prevent the spread of the new coronavirus infection.
- Discussions continue with Australia regarding capsule retrieval.



(image credit：JAXA)

2. Current Trajectory Plan



(image credit: JAXA)

6/11 current orbit

Earth distance	1.3 million km
Sun distance	2.1 million km

(passing the alphelion during the return trip on May 9)

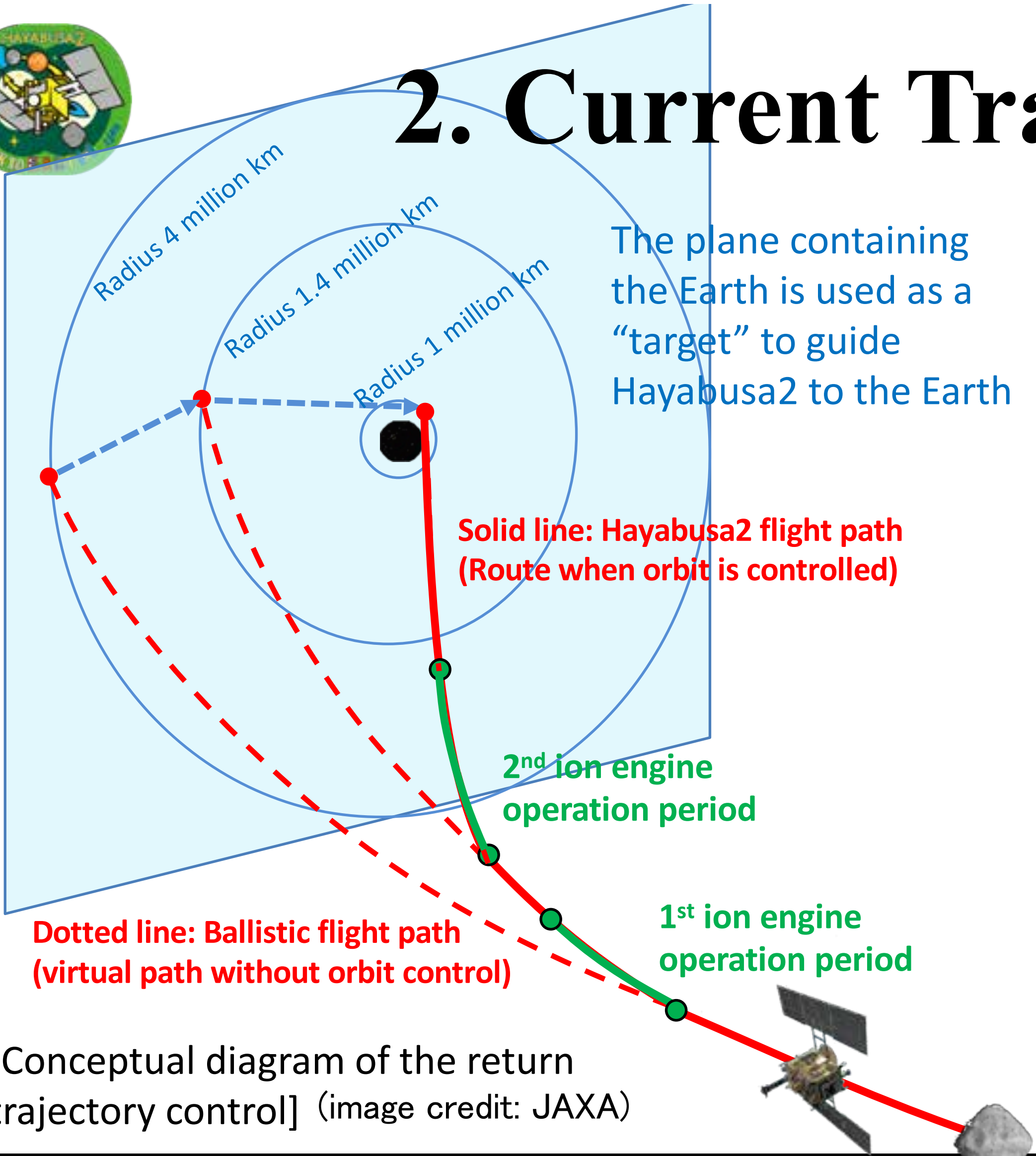
Ryugu distance	2.64 million km
Flight speed	23.0 km/s
Total flight distance	48.6 billion km

(380 million km remaining)

Return trip ion engine use 42% complete

The 1st ion engine operation was in the deceleration direction for timing adjustments. In the 2nd operation, ions were injected in the acceleration direction for final precision guidance.

2. Current Trajectory Plan

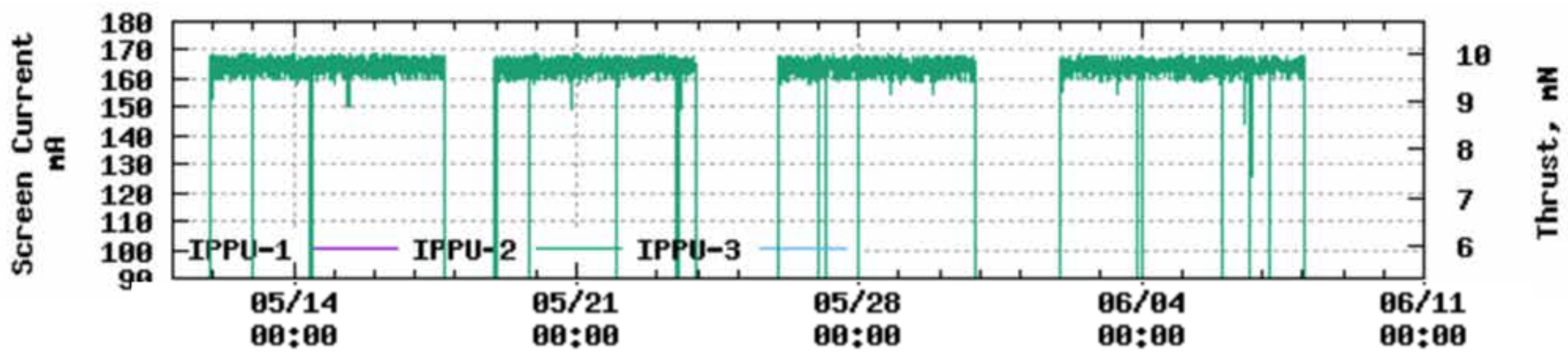


[Conceptual diagram of the return trajectory control] (image credit: JAXA)

- The 1st ion engine operation changed to an orbit where the closest approach to Earth was 1.4 million km, compared with the previous 4 million km.
- The 2nd ion engine operation plans to change the closest distance from 1.4 million km → 10,000 km or less (orbit passes just beyond the edge of the Earth).
- 2nd ion engine plan: By the end of August, the required injection amount will be exhausted and the ion engine temporarily stopped. The precise orbit will be measured, and precise orbit adjustments with the ion engine will be performed for about 1 week.
- All Hayabusa2 ion engine operations will be complete by the end of September.

3. 2nd ion engine operation status

- In the 1st ion engine operation for return phase, 881 hours of powered navigation and ⊿V=100m/s were achieved from Nov. 20, 2019 – Feb. 20, 2020 over a total of 7396 hours of flight.
- From May 12, 2020, the 2nd ion operation began.
- Currently, 1 ion engine is operating with a trust of about 9.7 mN. From August, the operation will be increased to 2. Between May – September, the total operating time will be 2014 hours with ⊿V=160m/s, and this is expected to complete the operation.
- About 3.5kg of xenon propellent will be consumed. As of the end of September, about 35 kg –about 55%-- remains.



*IPPU=ion engine power supply

（image credit：JAXA）

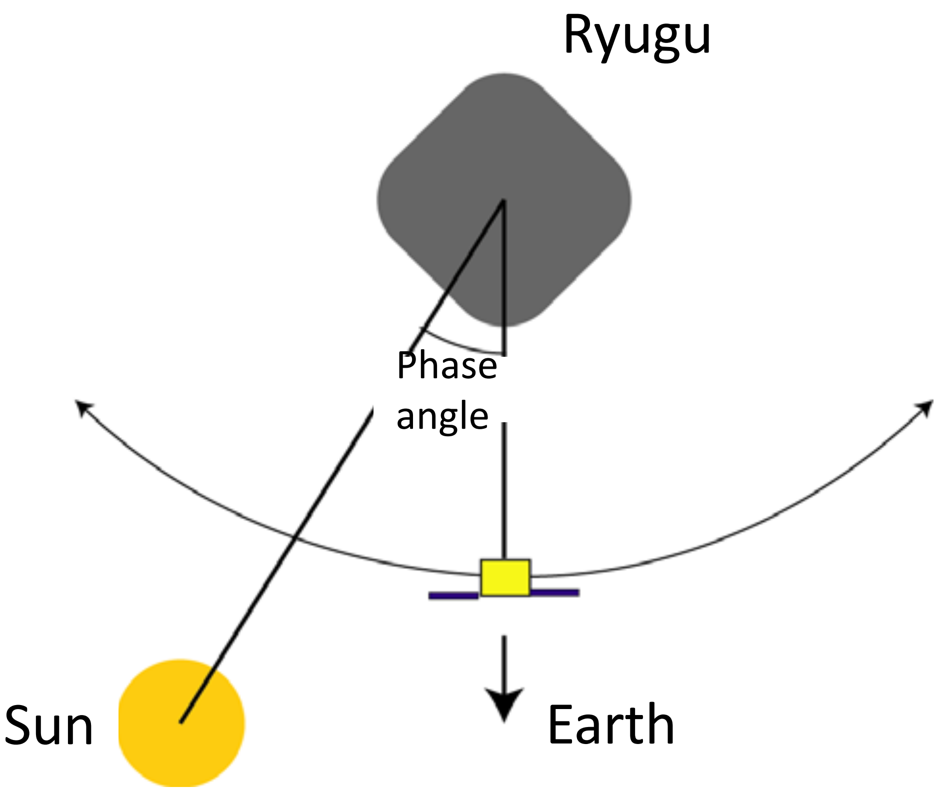
4. ONC photometric observations of Ryugu

"Global photometric properties of (162173) Ryugu"

Tatsumi et al. (2020) *Astronomy & Astrophysics*

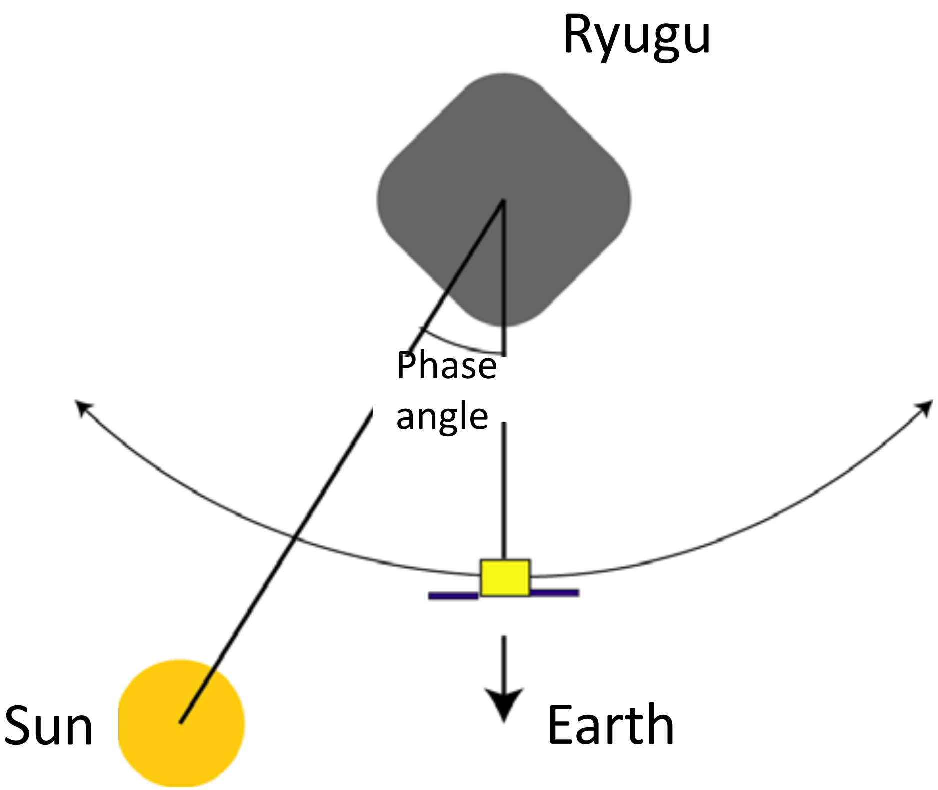
- Summary of the results from Ryugu photometric observations with the ONC over about half a year between 2018/07-2019/01.
- Comparing ground-based and ONC observations, the calibration accuracy of ONC was shown to be high as the two observation sets agree within the error range.
- The global reflectance map reveals the inhomogeneity in the reflectance of Ryugu.
- Results suggest the average geometric albedo of Ryugu is 4.0±0.5%, the standard reflectance is a dark 1.87±0.14% and the carbon content is as high as >2wt.%.
- A weak phase reddening (surface reddening with the increase of the phase angle) was confirmed with Ryugu. This suggests <u>fine particles are present on the surface</u>. The same degree of phase reddening was also confirm with Bennu, suggesting surface conditions may be similar.

4. ONC photometric observations of Ryugu

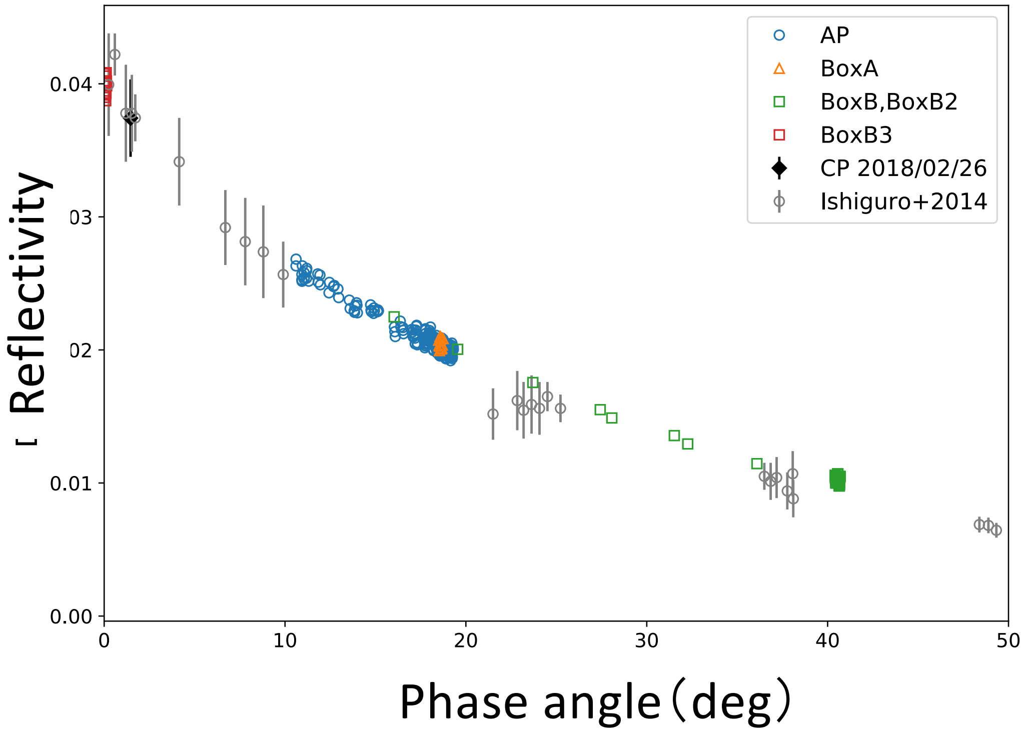


- The photometric function and reflectance (albedo) were obtained from Ryugu observations with the ONC for about half a year between 2018/07-2019/01.
  → Reflectivity depended on illumination and observation angle, so observations under a wide range of angle conditions were necessary.
- By changing the positional relationship between the Sun and Earth, Ryugu could be observed over a wide range of phase angles.
- This is clue to the asteroid surface conditions.

4. ONC photometric observations of Ryugu



Ryugu photometric function

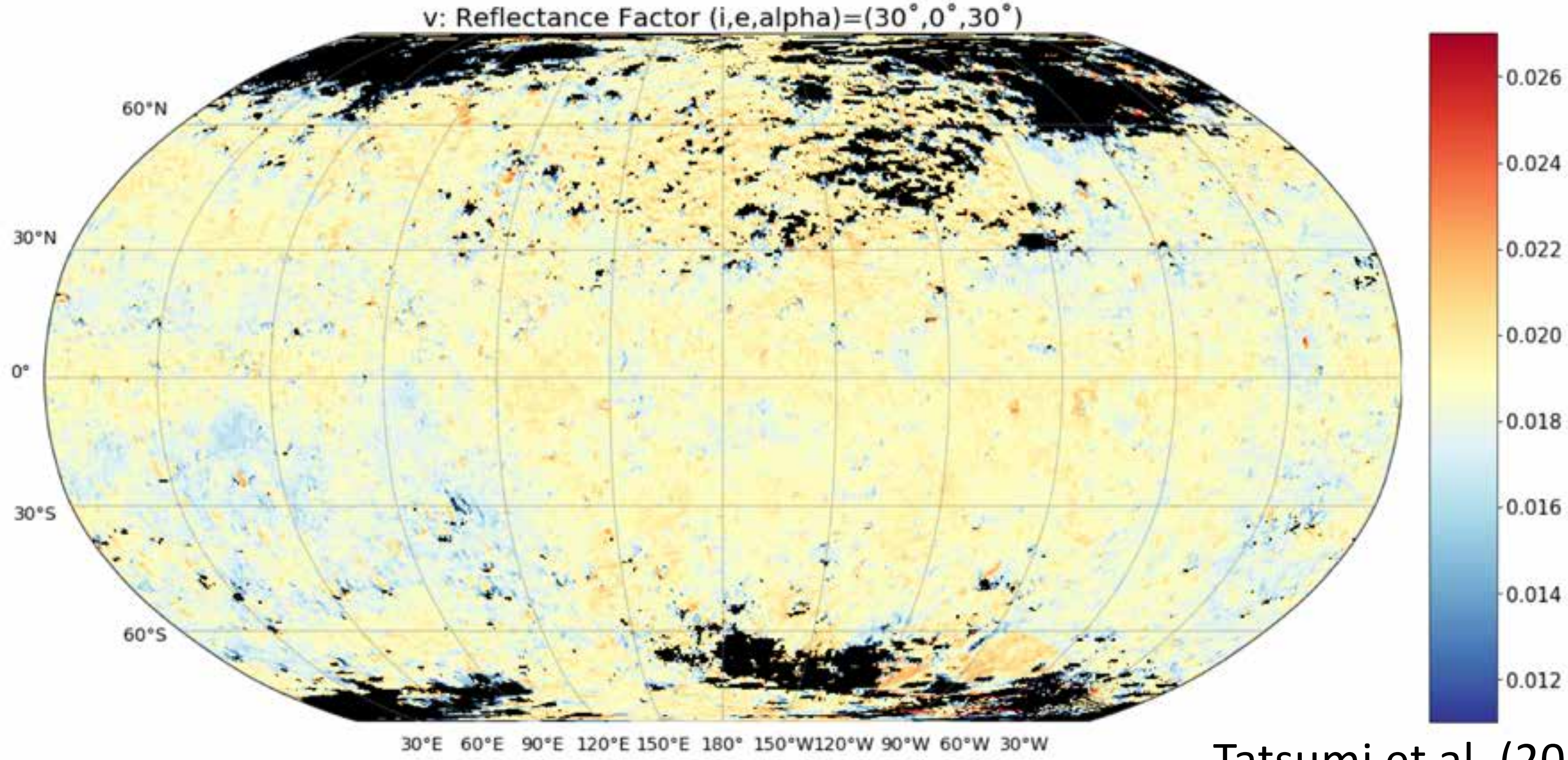


Color：ONC observation、Grey：ground observation

Tatsumi et al. (2020)

4. ONC photometric observations of Ryugu

- Global standard reflectance (albedo) map of Ryugu created from ONC observations

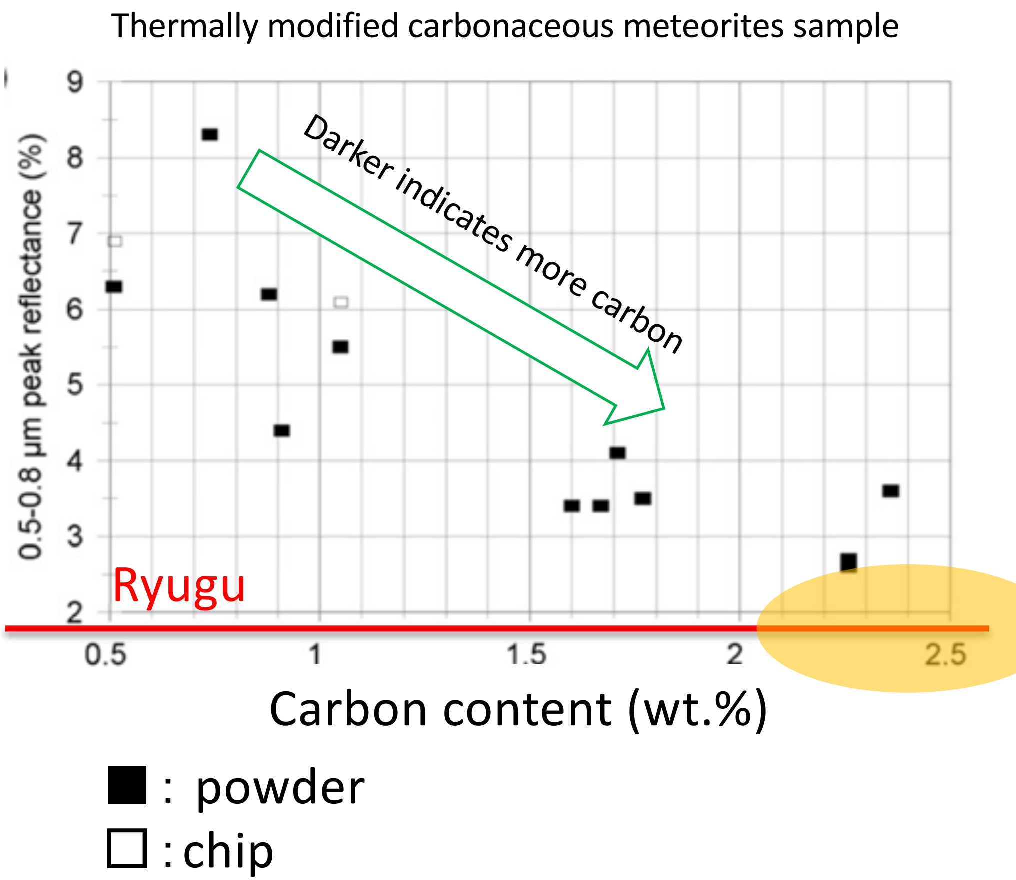


Tatsumi et al. (2020)

4. ONC photometric observations of Ryugu

- Comparison of ONC and ground observations show agreement of the spectra of Ryugu within error range.
  →ONC calibration accuracy guarantee
- Geometric albedo*: 4.0±0.5%
  Standard reflectance**(REFF(30,0,30)): 1.87±0.14%
  →Consistent with thermal metamorphic carbonaceous meteorites, carbon content expected to be >2wt.%

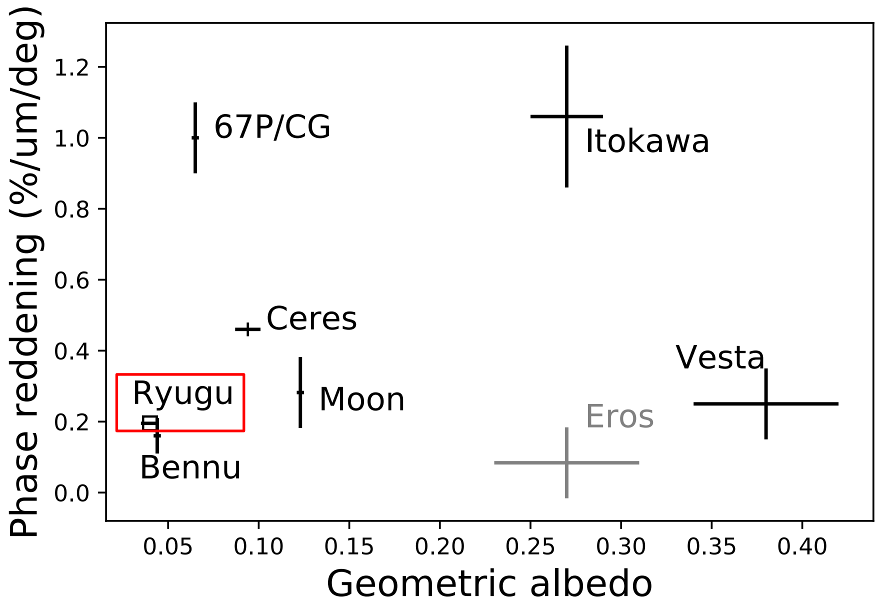
*Reflectance value when light is applied from the front and reflectance measured from the front.
**Reflectance when light shines from a direction tilted at 30 deg from the front and reflectance when brightness aimed from the front.



Cloutis et al. (2012)

4. ONC photometric observations of Ryugu

- The surface of Ryugu is observed to become slightly redder as the phase angle increased (phase reddening).
  - Suggests the existence of fine particle about the size of that wavelength length.
  - Shows multiple light scattering on the celestial surface. However, this effect is much weaker than that on Itokawa.
  - Phase reddening is similar to that on Bennu → the surface reflection may have similar characteristics.



Tatsumi et al. (2020)

5. Thermophysical property estimates of Ryugu with the TIR

"Thermophysical properties of the surface of asteroid 162173 Ryugu: Infrared observations and thermal inertia mapping"

Shimaki et al. (2020) *Icarus 348, 113835*

https://doi.org/10.1016/j.icarus.2020.113835 Posted：2020/5/16

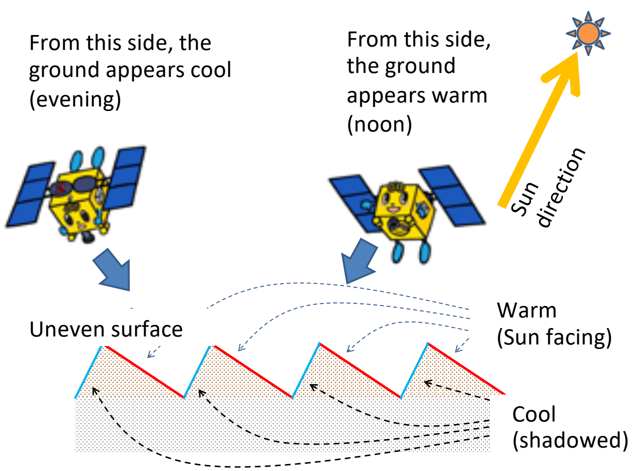
- Distributions of thermal inertia and roughness of Ryugu were estimated using TIR observations from 2018/8/1 and a thermal model calculation of the uneven surface.
- The thermal inertia of Ryugu was found to be uniformly low, and porous boulders were scattered evenly across the entire surface.
- The surface of Ryugu was found to be as rough as ʻAʻā lava※.
- The obtained thermal inertia and unevenness have a significant influence on the calculation of Ryugu's orbital evolution.

ʻAʻā lava（by Rina Nogouchi）

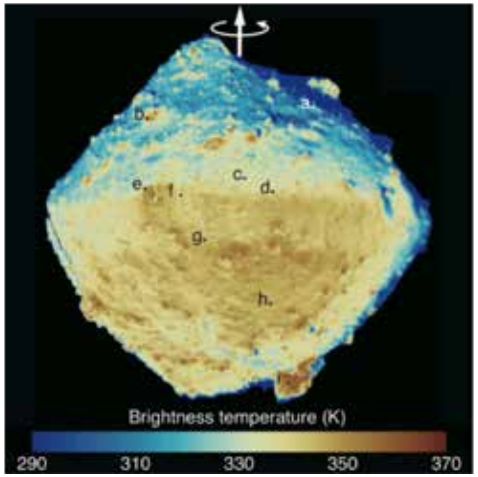
※ Ryugu is uneven on scales of several meters square, ʻAʻā lava is uneven over several tens of centimeters square.

5. Thermophysical property estimates of Ryugu with the TIR

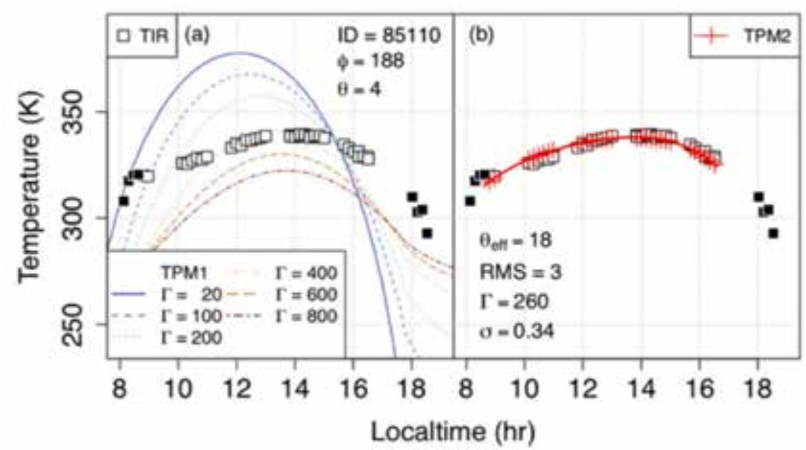
- From the thermal images with TIR and the thermal model calculation of the uneven surface, the effect of the roughness on the surface temperature was demonstrated.



Roughness effect
（©JAXA、Chiba Institute of Technology）



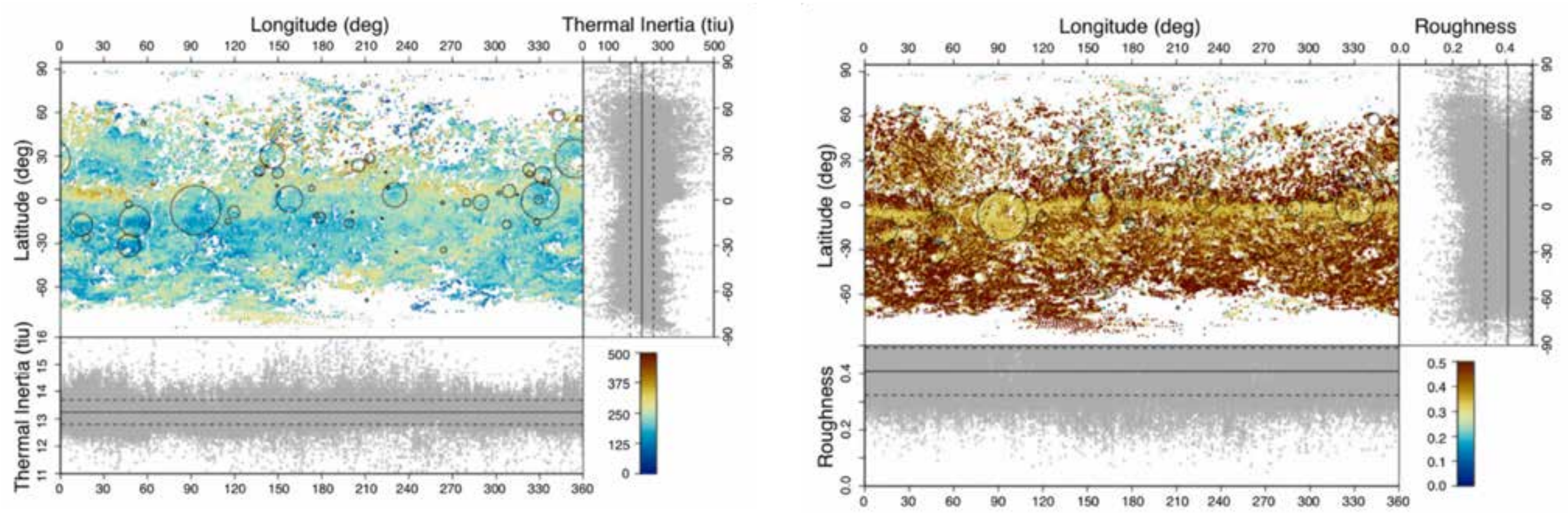
Thermography of Ryugu on 2018/8/1
（from Shimaki+, Icarus 2020）



（a）Temperature history without using the TIR and uneven thermal model calculation（TPM1）（b）Temperature history using the uneven thermal model calculation（TPM2）. Γ and σ are thermal inertia and unevenness, respectively.
（From Shimaki+, Icarus 2020）

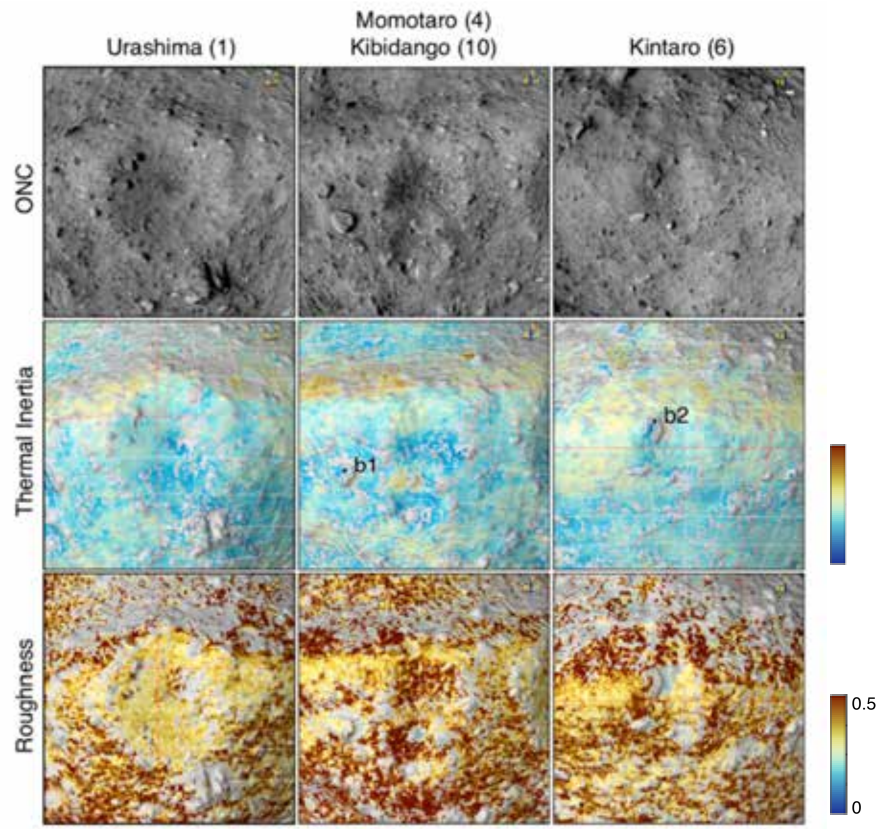
5. Thermophysical property estimates of Ryugu with the TIR

- Roughness effect：predicted from ground and flyby observations. With hovering observations & 2D imaging, high time and spatial resolution (4.5m) achieved.
- Global thermal inertia：225 ± 45 J m^{-2} $s^{-0.5}$ K^{-1}（tiu）（300 ± 100 tiu, Okada+, Nature 2020）→ Porous boulders scattered evenly over the surface. -- Dense rocks (basalt etc) >2000 tiu、porous carbonaceous chondrites 600-1000 tiu
- Global irregularity：RMS surface slope $47 \pm 5°$, similar to ‘Aʻā lava※、small at equatorial ridge → evidence suggests mass transfer between equator and mid-latitude. ※ Ryugu is uneven on scales of several meters square, ‘Aʻā lava is uneven over several tens of centimeters square

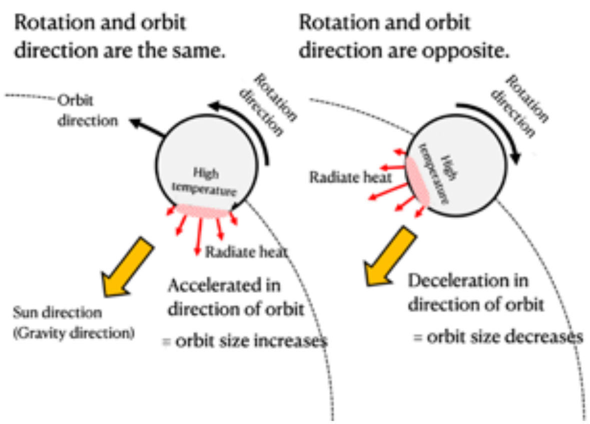


（Left）Ryugu thermal inertia map. ◯ mark the main craters.（Right）Ryugu roughness map.（modified from Shimaki+, Icarus 2020）

5. Thermophysical property estimates of Ryugu with the TIR



Large crater and boulder images with ONC, thermal inertia and roughness.（Shimaki+, Icarus 2020）



Yarkovsky effect（©JAXA、Chiba Institute of Technology）

- Large crater : Thermal inertia similar to the global average → No evidence of collision ejecta deposits or consolidation
- Large boulder : Thermal inertia can be lower than the global average. → Suggests low-density, "rubble"-like structure.
- Ripple effect : The obtained thermal inertia and roughness influences the Yarkovsky effect (orbit change) and YORP effect (rotation speed change) → significant impact on the calculation for Ryugu's orbital evolution.

6. Future plans

■Operation schedule

2020/5/12～ 2nd ion engine operation

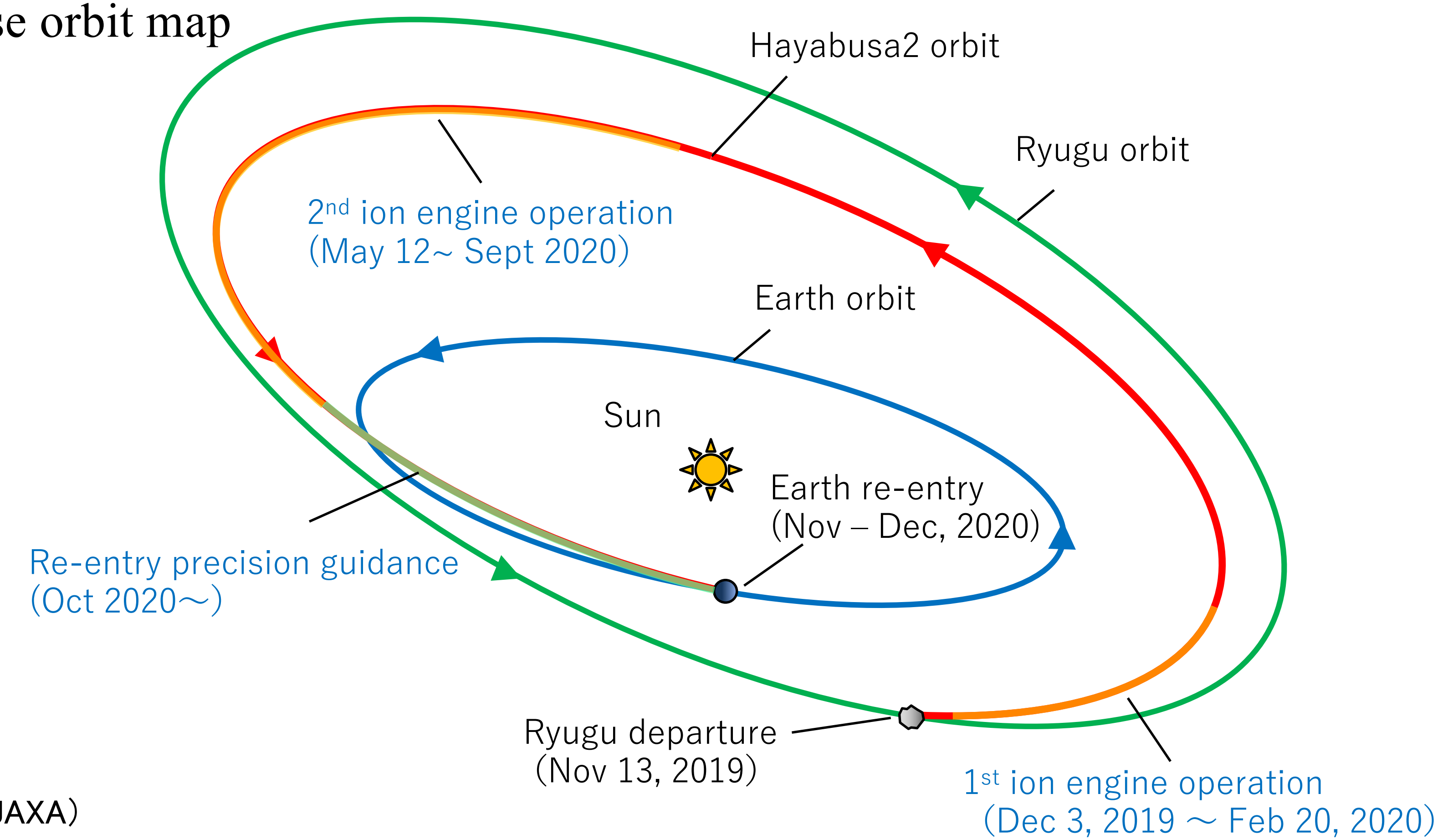
■Press & media briefings

2020/7（TBD)　　　Press briefing @TBD

Reference material

Return cruise operation plan

Return phase orbit map



（image credit：JAXA）

Electric propulsion (ion engine)

- Name: μ10
- Converts xenon* into plasma (ions), which is accelerated by applying voltage.
- A microwave discharge system is used to generate ions.
- Four units are mounted, and simultaneous operation of three generates thrusts of up to 28 mN.
- Approximately 60 kg of loaded xenon fuel, allowing acceleration up to 2 km/s.
- It is used to alter trajectories when cruising from Earth to the asteroid and back.

Injection test by a flight model in a vacuum chamber

Hayabusa 2 ion engine

*Why we use xenon

- Xenon is a monoatomic molecule, so its ionization voltage is smaller than that of gasses comprising two or more atoms. This increases the ratio of added energy that is used for acceleration.
- Reactivity is lower than that of other substances.
- Mass (atomic weight) is large, improving the efficiency of acceleration.

Reference：how the ion engines work

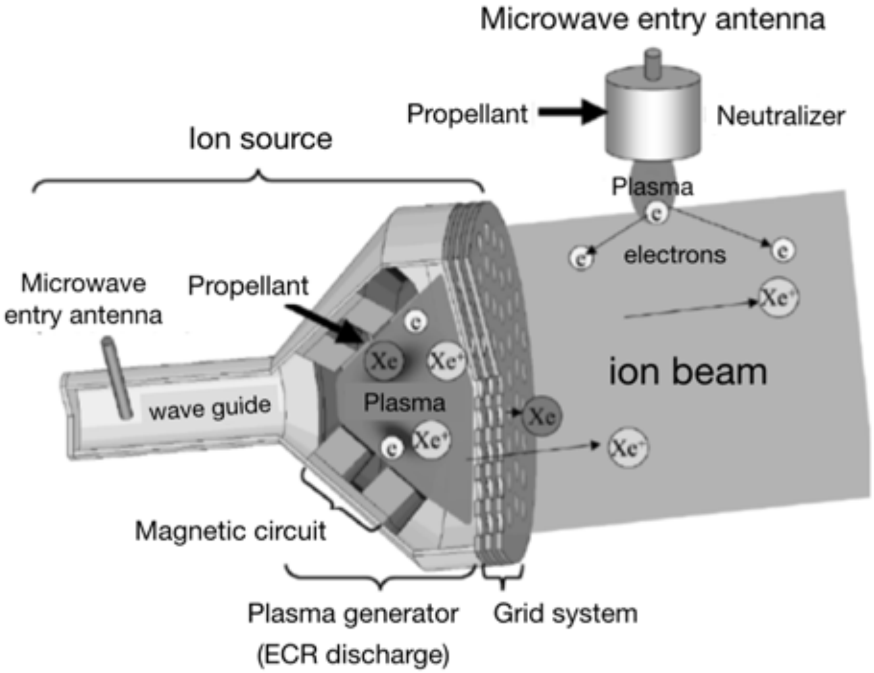


Fig: Schematic diagram of microwave discharge type ion engine

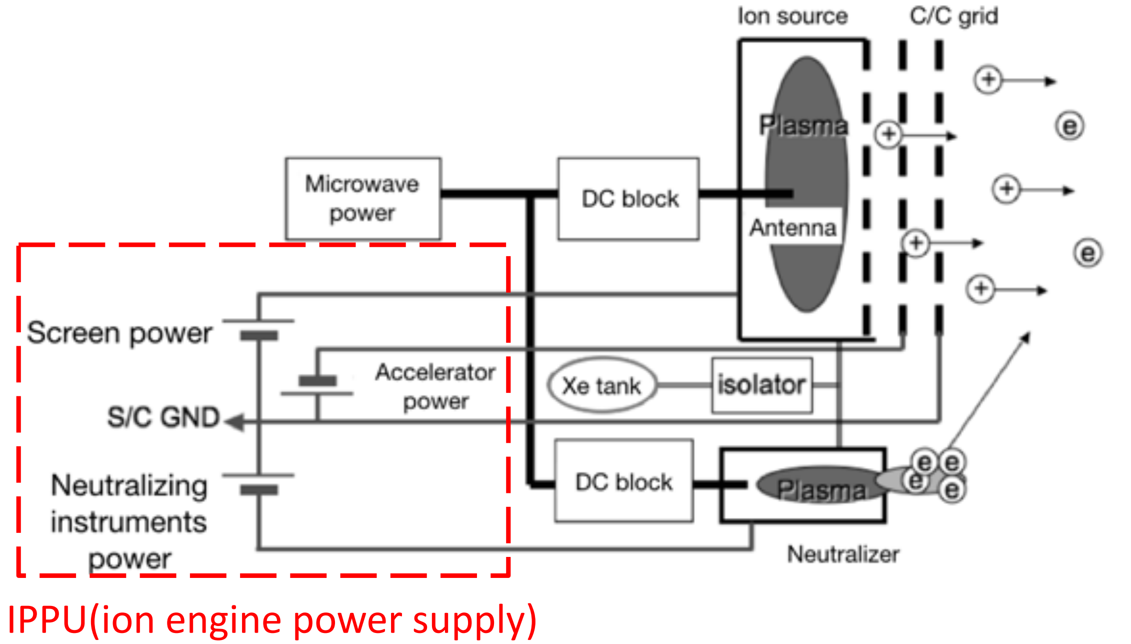


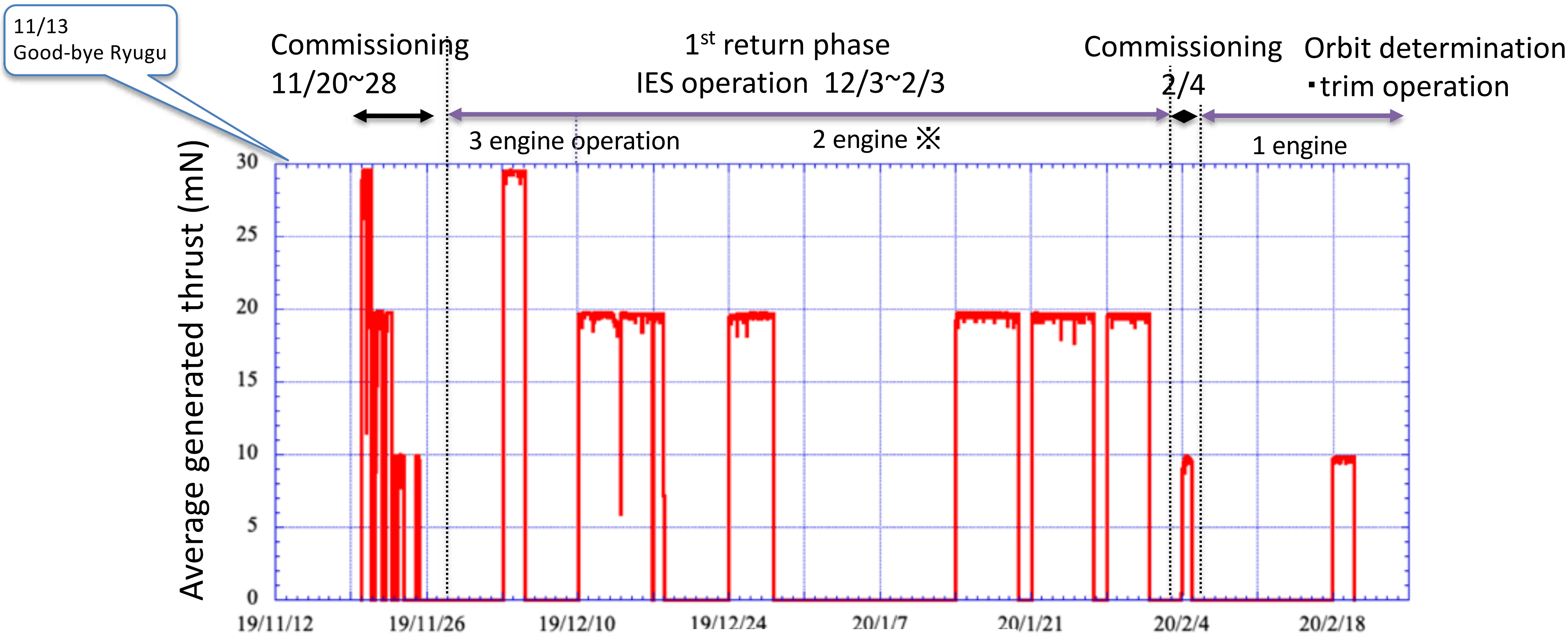
Fig: System diagram of microwave discharge type ion engine

（credit：JAXA）

Note: the ion engine developed at Institute of Space and Astronutical Science in Japan is a microwave discharge ion engine

1st ion engine operation results

Ion engine operation history after leaving Ryugu (2019.11.20 – 2020.2.20)



（credit：JAXA）

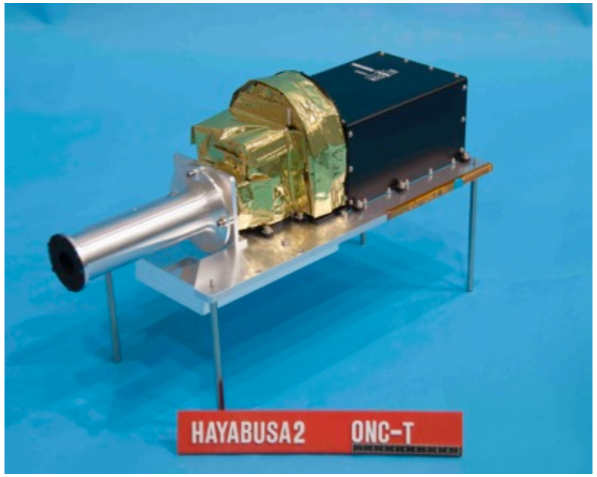
※Decrease in number due to increase in solar distance

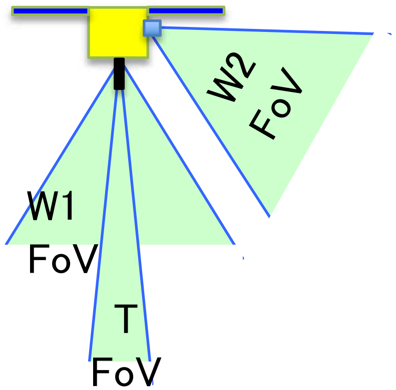
Optical navigation camera (ONC)

Optical Navigation Camera

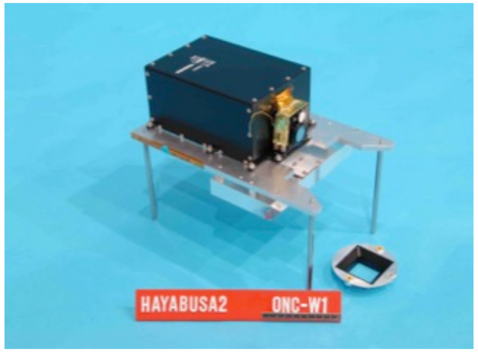
<u>Objective</u>: Images fixed stars and the target asteroid for spacecraft guidance and scientific measurements

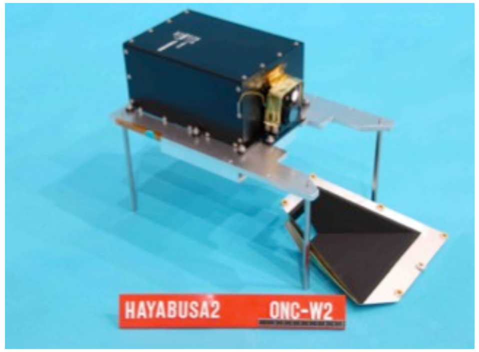
	ONC-T	ONC-W1	ONC-W2
Detector	2D Si-CCD (1024 x 1024 px)		
Viewing direction	Down (telephoto)	Down(wide)	Side (wide)
Viewing angle	6.35° × 6.35°	65.24° × 65.24°	
Focal length	100m～∞	1m～∞	
Spatial resolution	1m/pix @alt. 10km 1cm/pix @alt. 100m	10m/pix @alt.10km 1mm/pix @alt.1m	
Observation wavelength	color (390、480、550、700、860、950、589.5nm、 Wide)	monochromatic (485nm～655nm)	





（image credit：JAXA）



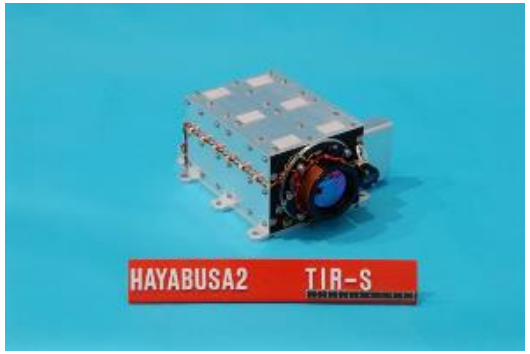


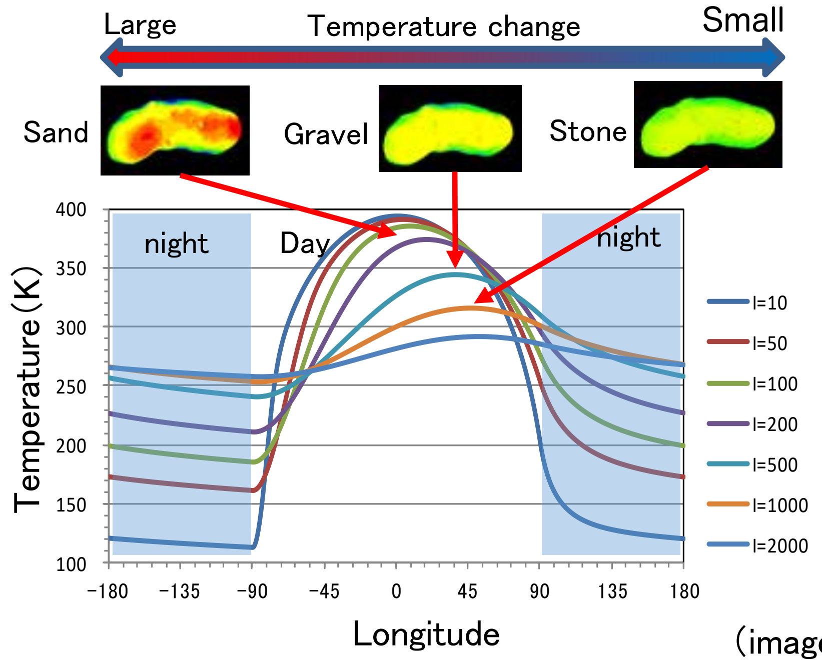
Thermal Infrared Imager：TIR

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 temperature	−40～150℃
・Relative accuracy	0.3℃
・Dimensions	328×248 (effecitive)
・Viewing angle	16° ×12°
・Resolution	20m (Alt. 20km)、5cm (Alt. 50m)





(image credit：JAXA)