I "semi della vita" tra le rocce dell'asteroide Ryugu

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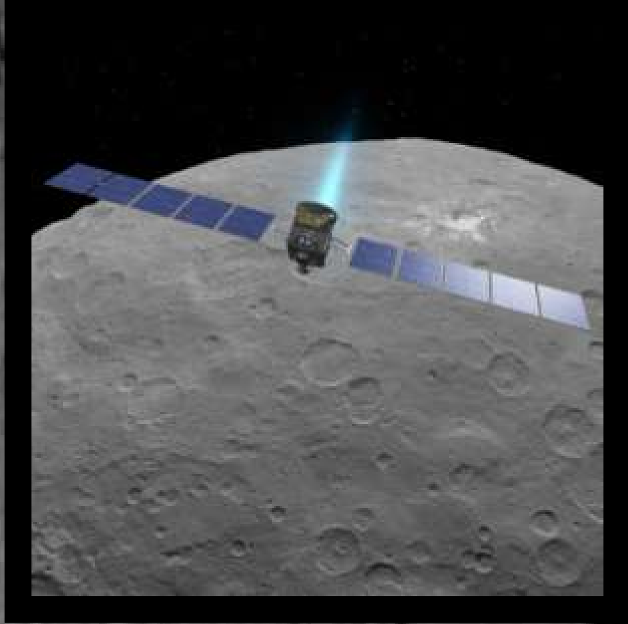
Scuola Estiva di Astronomia “Sergio Fonti”
"Asteroid and Comets: Bringers of Doom or Givers of Life?

24-25 Giugno 2024
Dipartimento di Matematica e Fisica “Ennio De Giorgi” - Università del Salento – Via per Arnesano, Lecce

…dall'osservazione del cielo dalla mia casa di campagna…

…all'analisi dei dati acquisiti da sonde spaziali…



Istruzione e formazione

- [redacted] Scientifico «V. Lilla», Oria (Br)
- [redacted] Fisica presso Università del Salento (Lecce)
- Fisica, Specializzazione in Astrofisica e Fisica della Terra presso Università del Salento (Lecce)
- 21/12/2018: **Dottorato in «Astronomy, Astrophysics and Space Science»** presso l'Università di Roma Tor Vergata (Roma) in collaborazione con IAPS-INAF (Roma)

Titolo della borsa di dottorato: *Unveiling the dwarf planet Ceres by means of VIR-Dawn hyperspectral data*

Titolo della tesi: *Spectral analysis of crater central peak material (ccp): indication about Ceres subsurface mineralogy*

Percorso Professionale

- 2019-2020: Assegnista di Ricerca presso lo IAPS-INAF

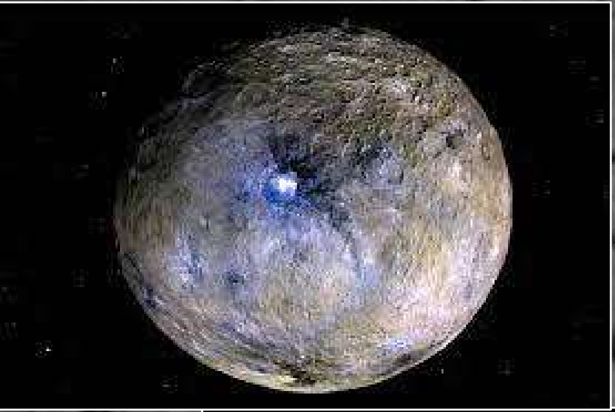
Titolo del Progetto: 2019-08-AR "*Hayabusa2 color and spectral data analysis and possible correlation with geomorphology of the asteroid Ryugu*"

- June 2018-today: Member of the **Hayabusa2 Joint Science team** (HJST), as NIRS3 Associate Member, spectrometer onboard Hayabusa2 spacecraft
- June 2019-today: IAU Junior Member
- 2021: **Honor Award** from the Hayabusa2 project to the scientists and engineers involved in the mission
- 2020-oggi: Assegnista di Ricerca presso lo IAPS-INAF

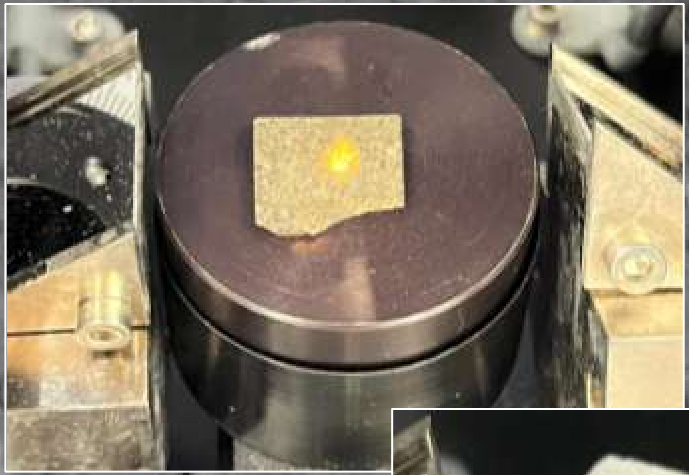
Titolo del Progetto: *2020-19-AR "Analisi spettroscopica e caratterizzazione mineralogica delle superfici solide di corpi del Sistema Solare con particolare attenzione al caso di Mercurio"*

- 2020-today: Associate member of **SIMBIO-SYS** instrument suite onboard BepiColombo mission
- 2020-today: Member of the **BepiColombo Surface and Composition Working Group** (SCWG)
- 2018-today **Principal Investigator** e **Co-Investigator** di svariati progetti

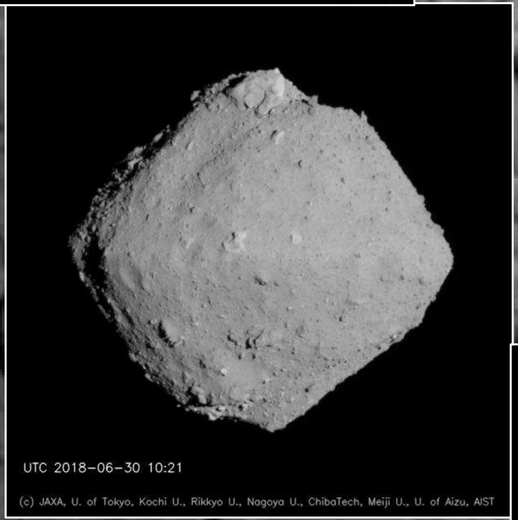
Area di competenza: *caratterizzazione delle superfici di pianeti e corpi minori del Sistema Solare tramite analisi di dati spettrali acquisiti in remote-sensing e mediante lo studio in laboratorio di meteoriti*



Ceres
VIR-Dawn

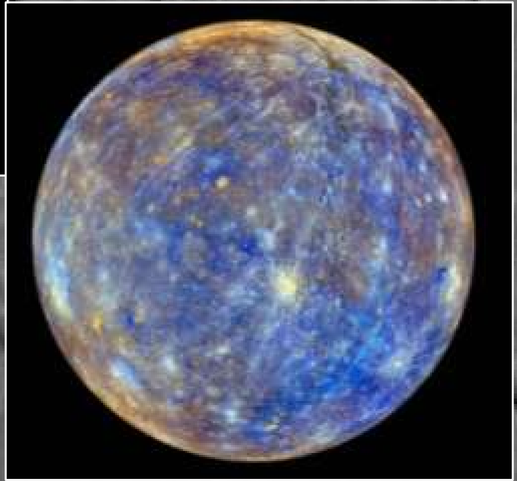


CO3



Ryugu
NIRS3-Hayabusa2

CV3

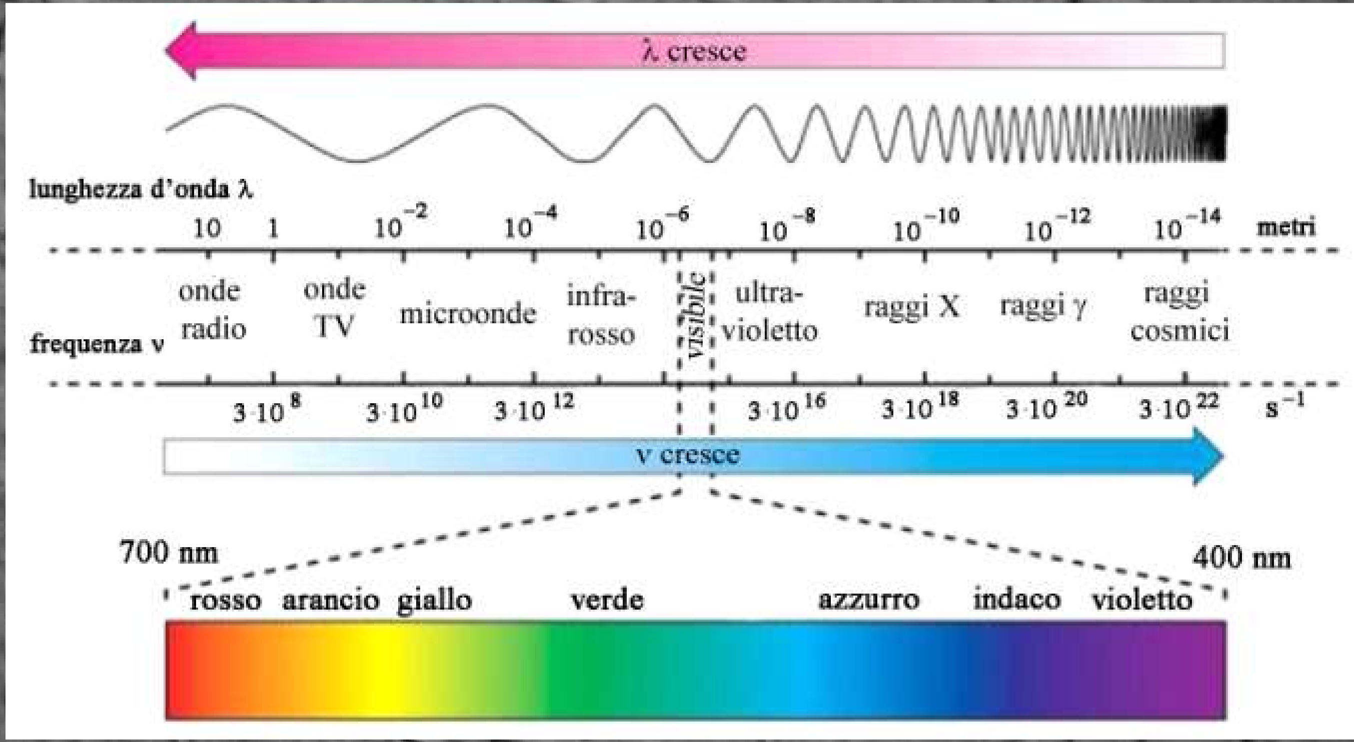


Mercury
MASCS-MESSENGER
MDIS-MESSENGER

CM2

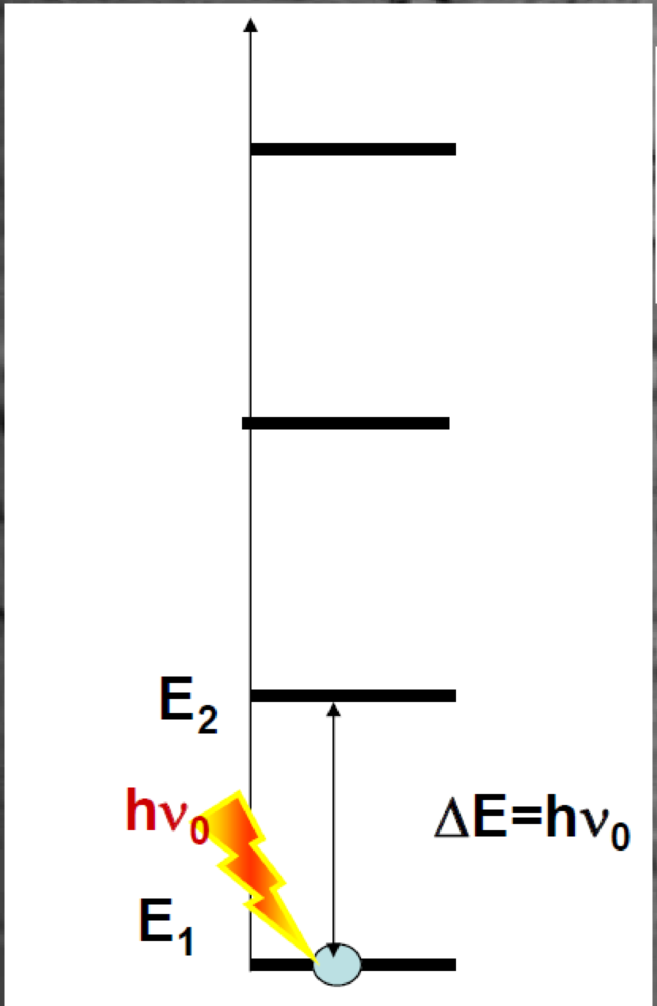
The IR Spectroscopy

The spectroscopy is a technique based on the absorption of the incident radiation from the molecules to reach an excitation level.
The IR radiation (0.7-1000 µm) is absorbed when the energy of the radiation is equal to the difference of energy between the fundamental and the excited level.
Information on the molecular and rotational vibrations, i.e. on the molecules in the minerals that absorb the IR radiation



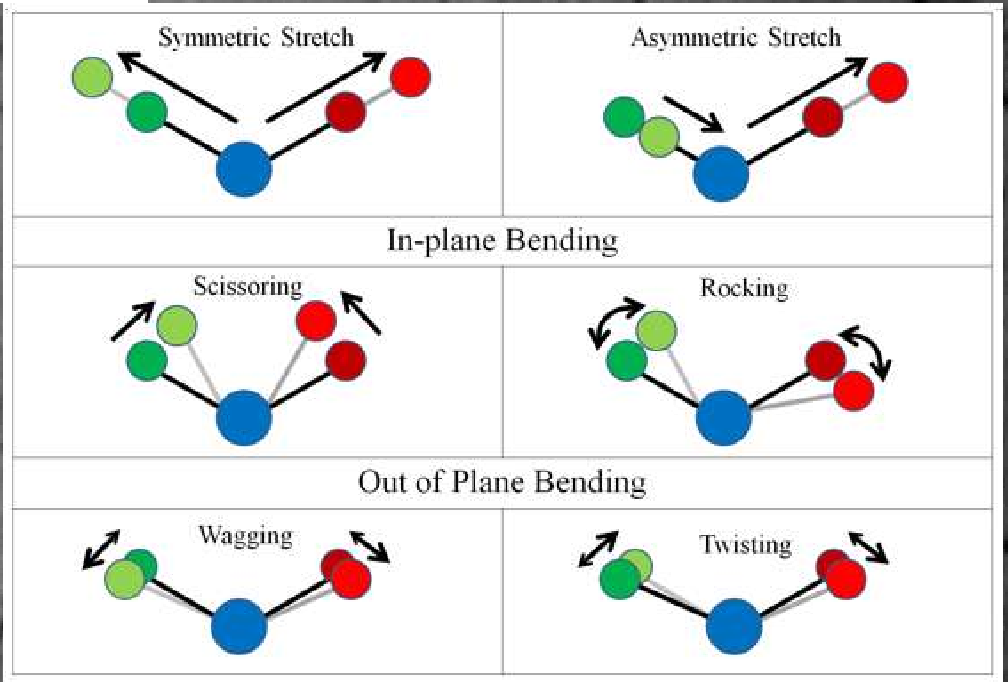
The IR Spectroscopy

- The IR radiation interacts with the molecule
- The IR radiation can produce changes in the vibrational energy of 2 or more atoms
- If the vibrations change the dipole moment of the molecule, the IR radiation is absorbed (IR active)
- The frequence of the absorbed radiation is indicative of the frequency of the molecule's motion and therefore of the molecule responsible of the absorption



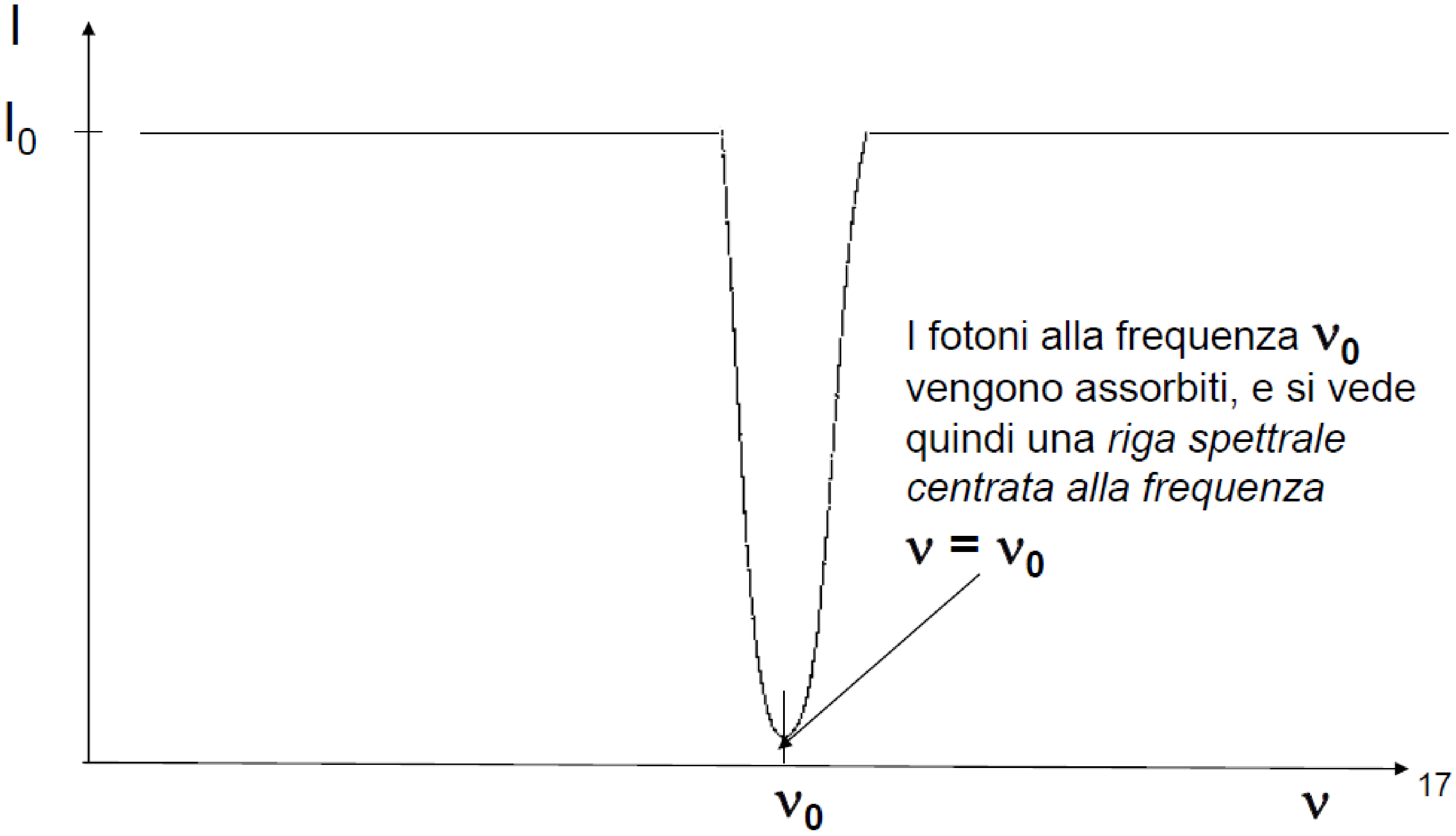
$$\nu = \frac{1}{2\pi}\sqrt{\frac{k}{\mu}}$$

$$\mu = \frac{m_A m_B}{m_A + m_B}$$

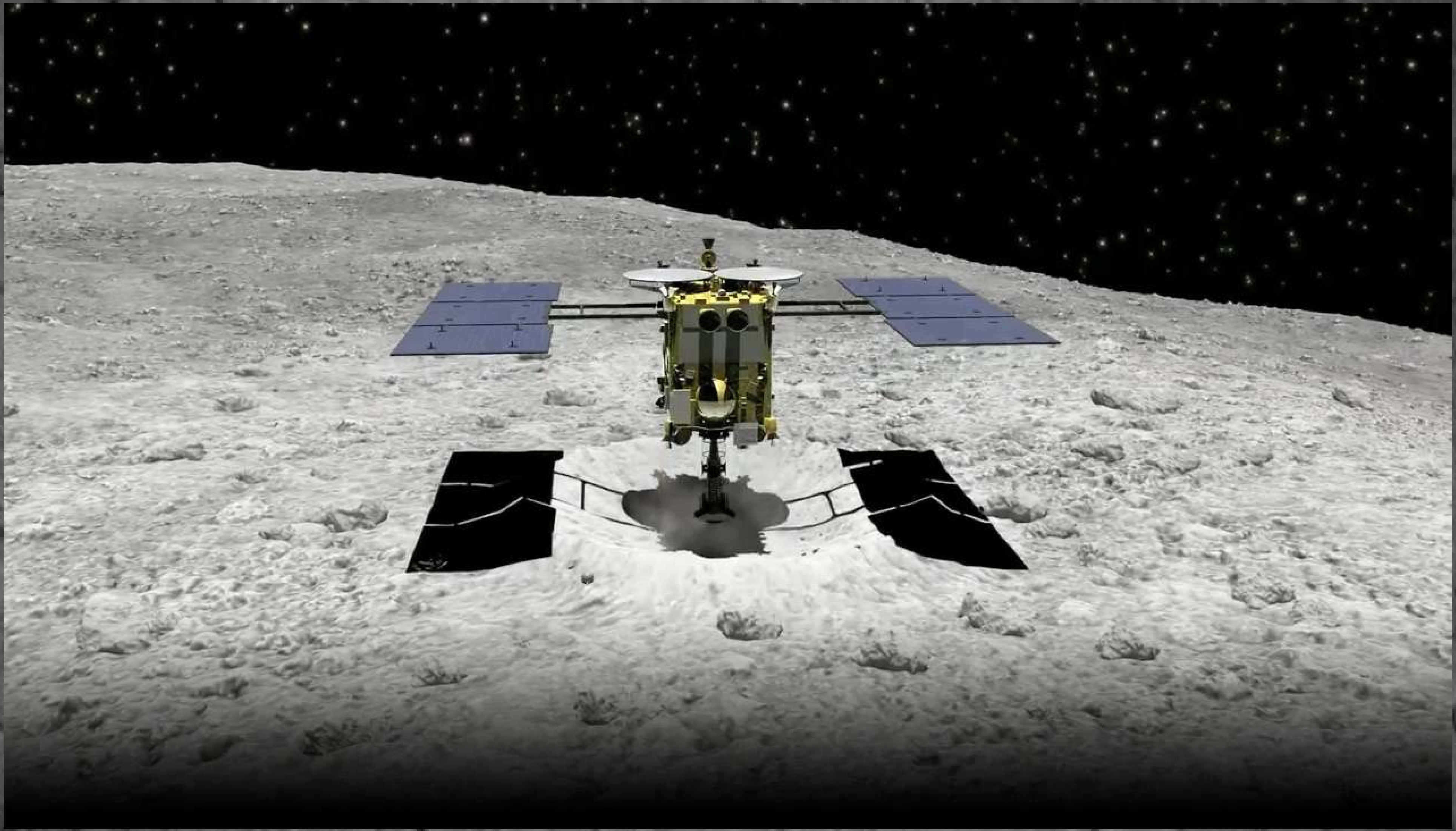


Spettro di assorbimento

La radiazione IR di intensità I_0 attraversa il campione. La sua FREQUENZA viene variata, e la radiazione non viene assorbita finché la frequenza $\nu = \nu_0$



The Hayabusa2 Mission



Target of the Hayabusa2 nominal mission: 162173 Ryugu

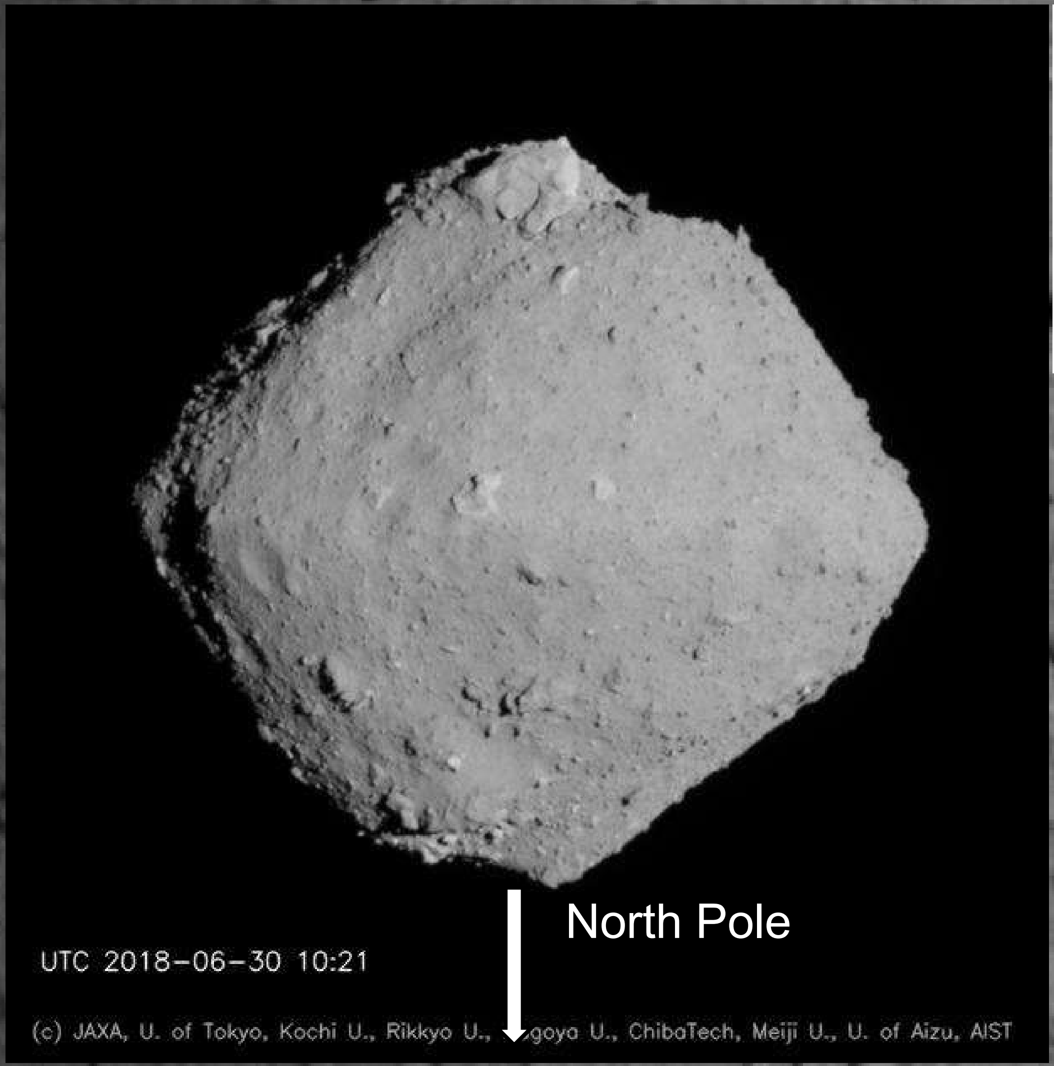
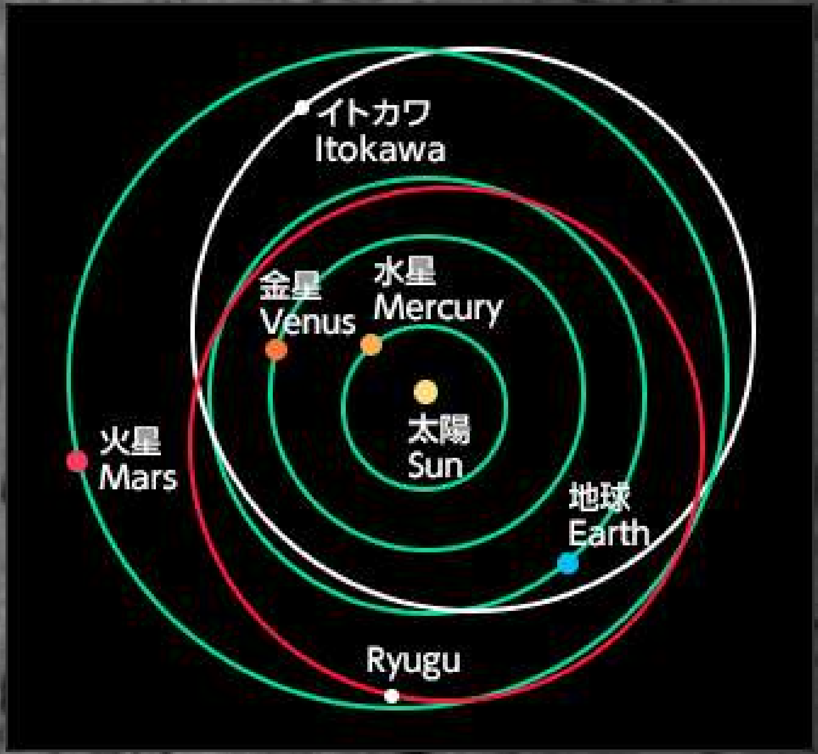
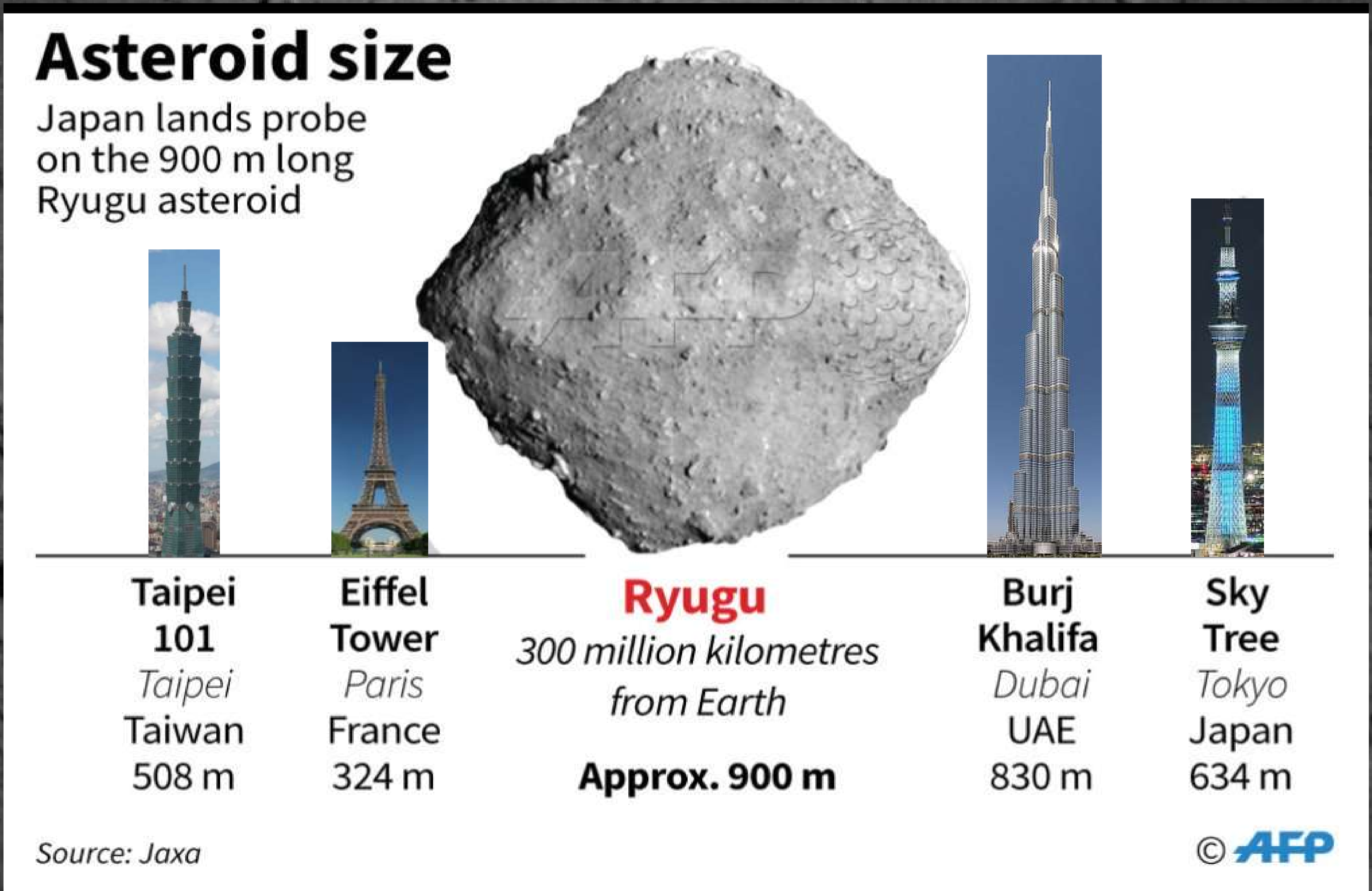


Image of Ryugu acquired by the ONC-T on June 26, 2018 at an altitude of 22 km km

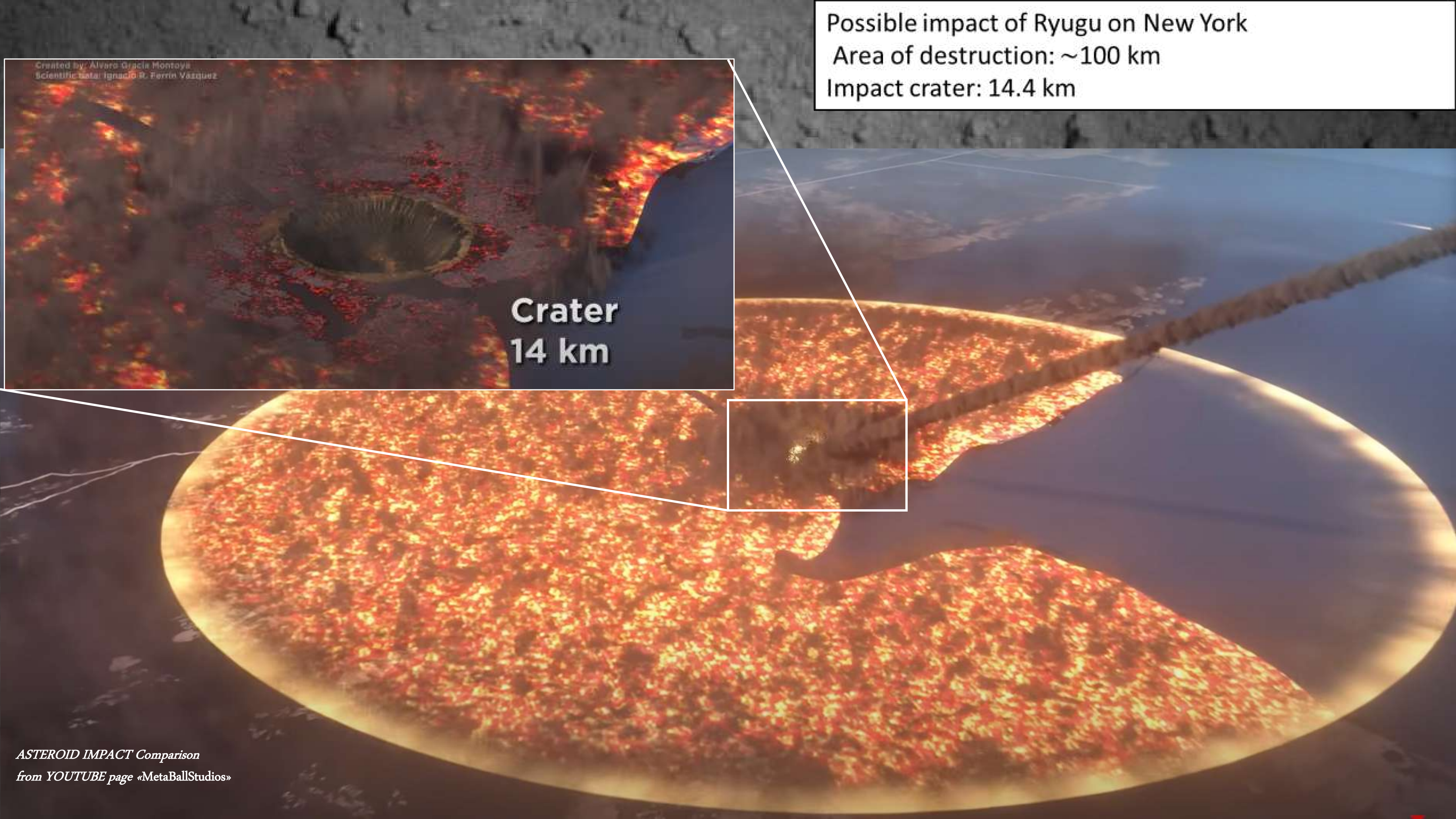
*Discovery:*May 1999
Equatorial radius: 502±2 m
Top-shaped asteroid
Rotation period: 7.63 h
Revolution period: 1.3 yr
Semi-major axis: 1.19 AU

Potentially azardous asteroid of the Apollo group

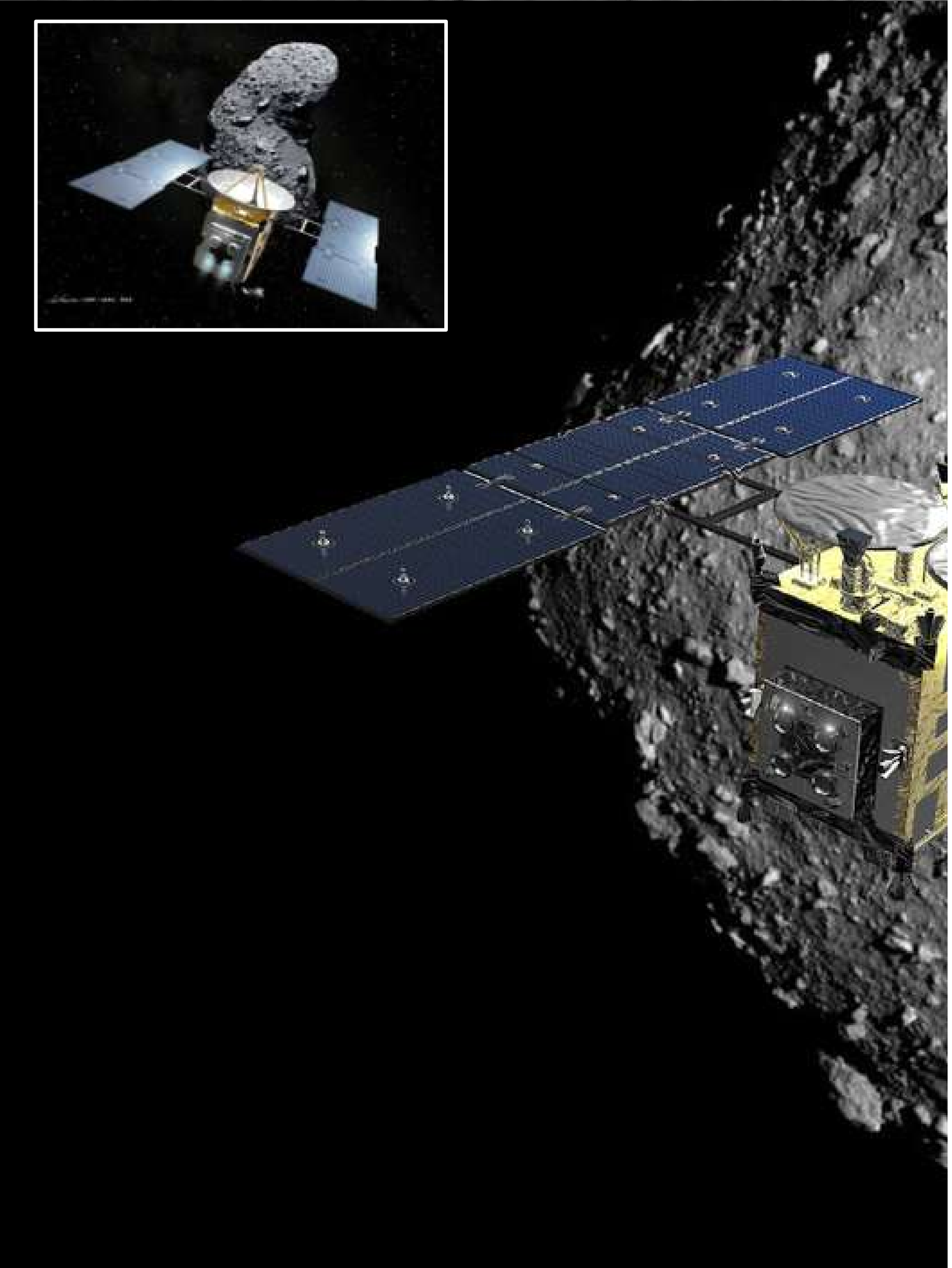



Asteroid size
Japan lands probe on the 900 m long Ryugu asteroid
Taipei 101
Taipei
Taiwan
508 m
Eiffel Tower
Paris
France
324 m
Ryugu
300 million kilometres from Earth
Approx. 900 m
Burj Khalifa
Dubai
UAE
830 m
Sky Tree
Tokyo
Japan
634 m
Source: Jaxa
© AFP

Possible impact of Ryugu on New York
Area of destruction: ~100 km
Impact crater: 14.4 km



ASTEROID IMPACT Comparison
from YOUTUBE page «MetaBallStudios»



Objectives

The Hayabusa2 mission is an asteroid-sample return mission, developed by the Japan Aerospace Exploration Agency (JAXA). It follows from the Hayabusa, sample-return mission that visited the Near-Earth asteroid Itokawa and returned sample to the Earth (in 2010)

The mission plans to study and sample the primitive C-type asteroid Ryugu, with the aim to pursue the following scientific objectives:

- Solve misteries related to the material's evolution in the solar system: processes between minerals, water and organic material which occurred during the early phases of Solar System will be clarified. By studying a C-type asteroid, which is rich in water and organic material, the interactions between the building blocks of Earth and the evolution of its oceans and life will be explained.

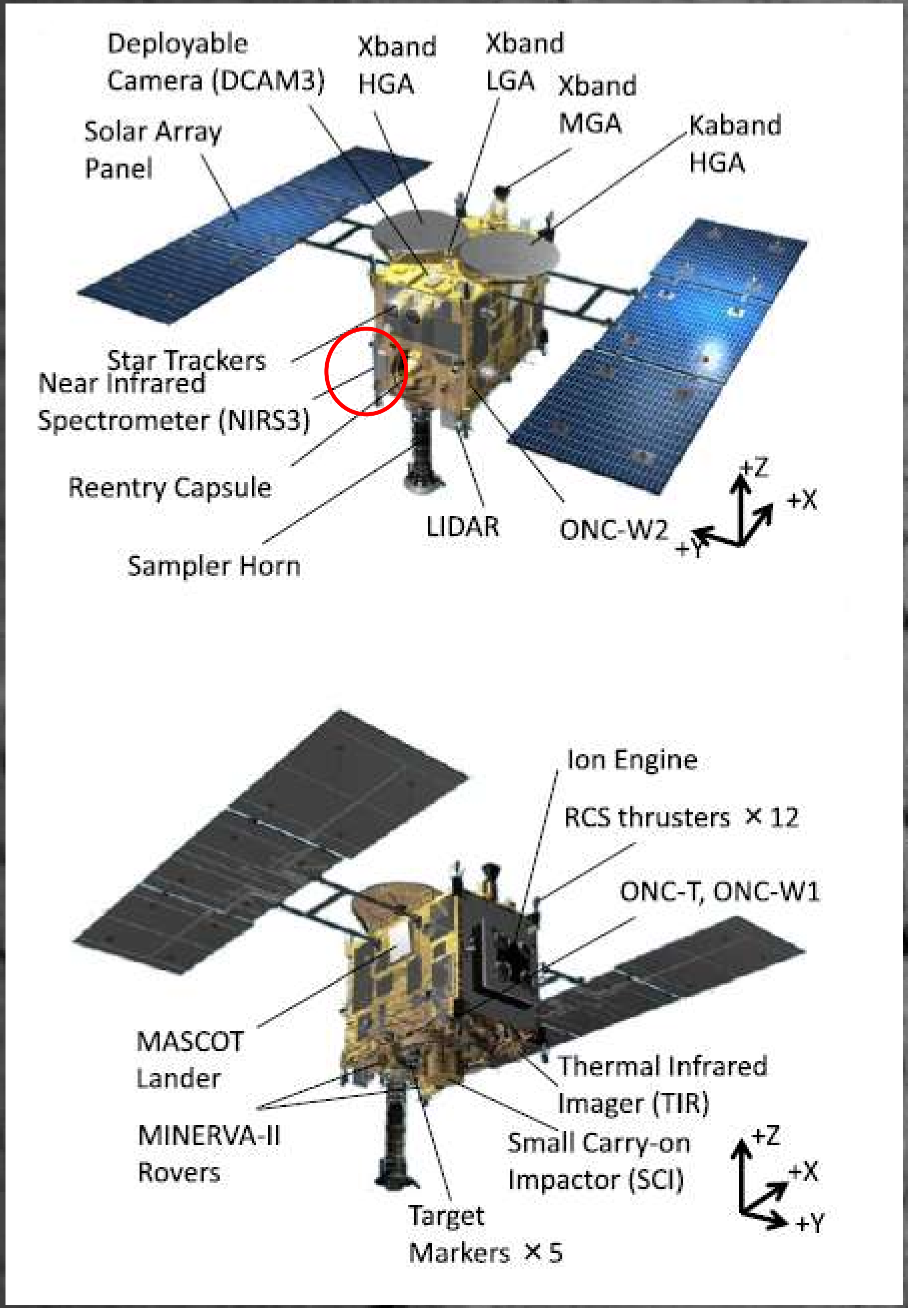
- Solve misteries related to the evolutionary process of asteroids: the formation process of asteroid will be examined by directly studying the materials into asteroids, their internal structure, and the subsurface material.

Hayabusa2 spacecraft

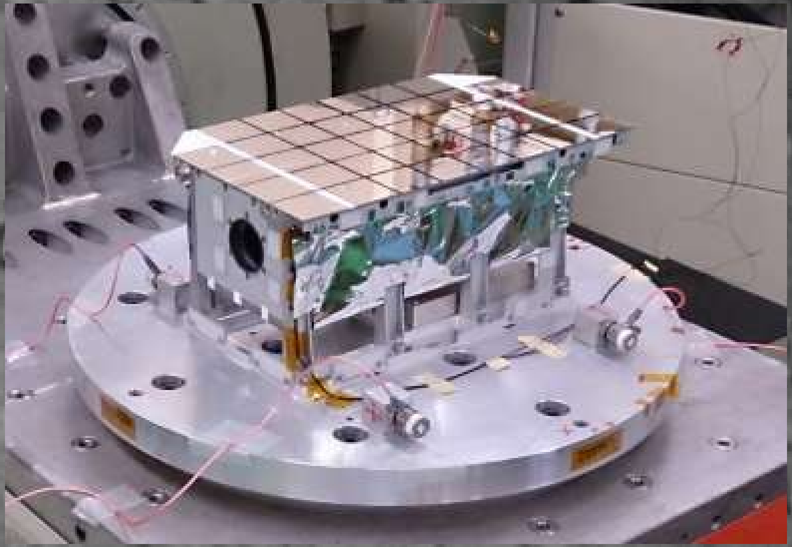
Height: 1.25 m
Width: 1.0 m
Depth: 1.6 m
Wet: 600 kg

Hayabusa2 was launched on December 3, 2014 by an H-IIA Launch Vehicle from Tanegashima Space Center in Japan

Spacecraft and Payload

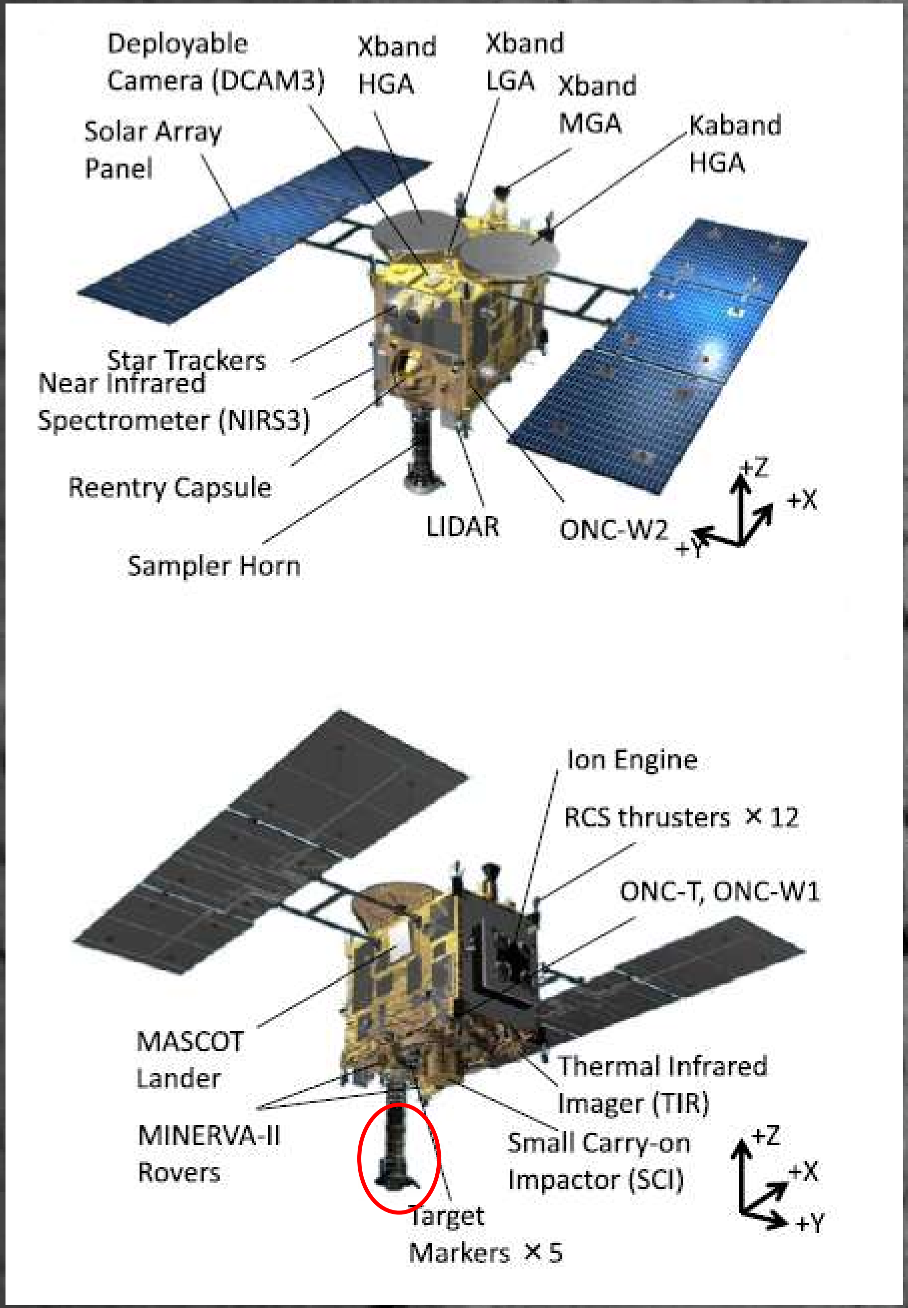


Near-infrared spectrometer NIRS3

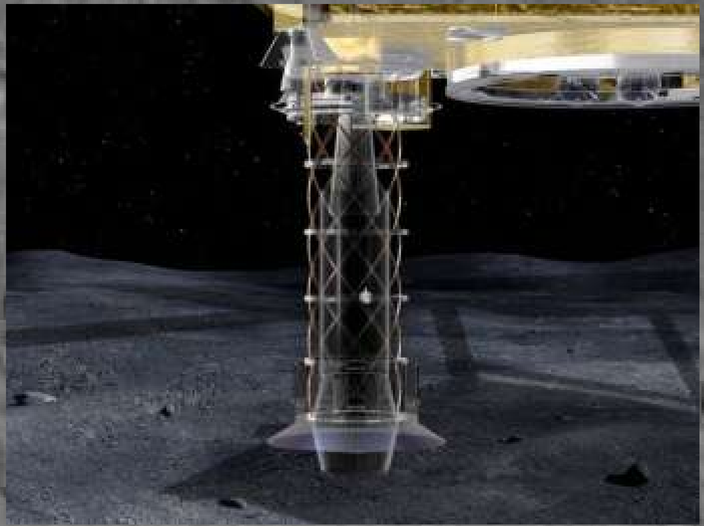


- Observation wavelength range: 1.8–3.2 μm
- Spectral resolution: 18 nm
- Full field of view: 0.1 deg
- Spatial resolution: 40 m (20-km alt.)
  2 m (1-km alt.)
  10s cm during descent operation
- Detector temperature: –85 to –70 °C
- Main objective: map the distribution of the hydrated minerals

Spacecraft and Payload



Sampling device SMP

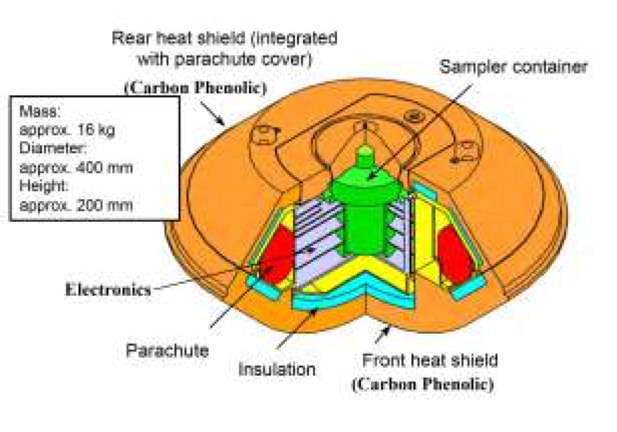


•As soon as the tip of the cylindrical horn touches the asteroid surface, a projectile is shot from within the horn and rising surface ejecta are caught in a catcher in the upper part of the horn.

•The sample catcher contains three chambers and it is located within the sample container of the Return Capsule.

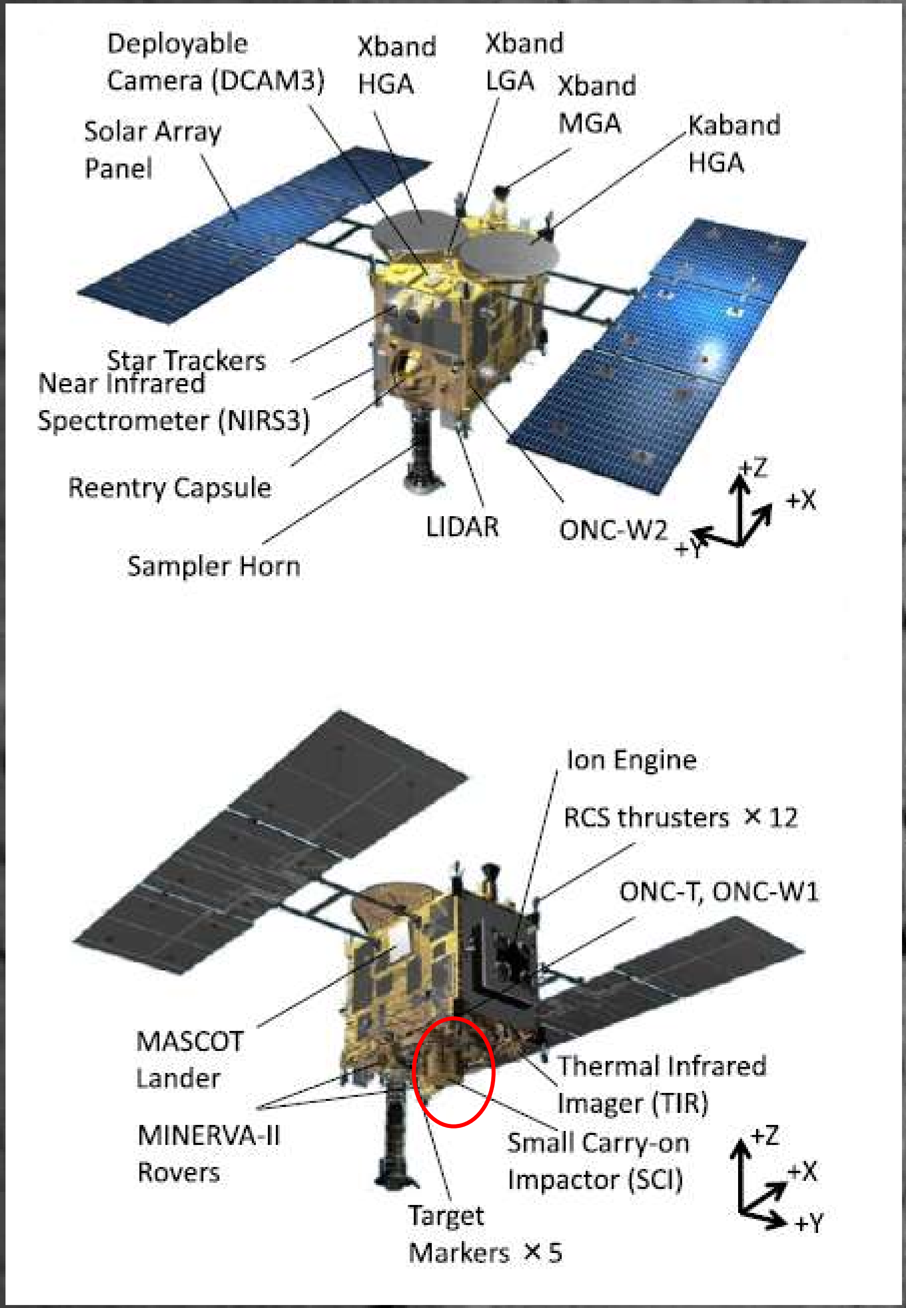
•There are small folded parts on the tip of the horn. Grains of 1–5 mm are caught in these folds.

Re-entry capsule

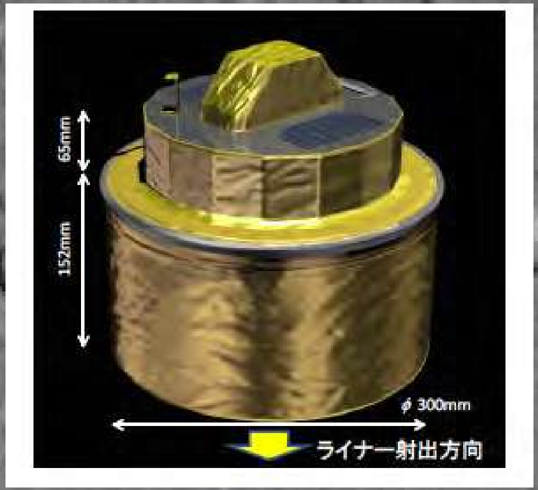


Speed during the re-enter:12 km/s,
The capsule separates from the spaceship while spinning at one revolution per 3 seconds.
It opens a parachute at an altitude of about 10 km.

Spacecraft and Payload

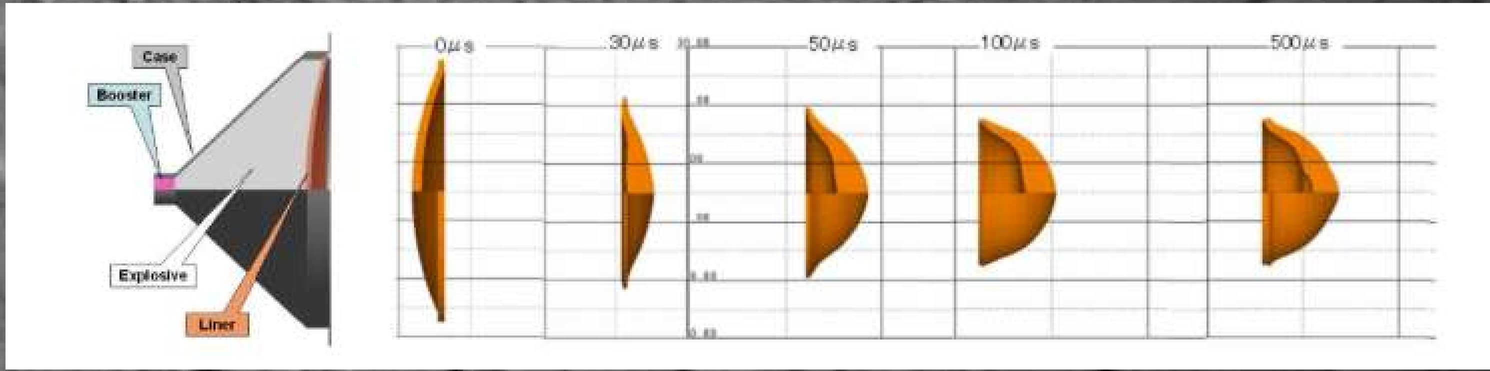


Impactor SCI - Small Carry-on Impactor



Form: Cylindrical (diameter 265 mm)
Liner (becomes projectile): Pure copper
Explosive: HMX-type PBX
Mass: Approx. 9.5 kg
Mass of explosive: 4.7kg
Mass of liner: 2.5 kg
Liner thickness: Approx. 5 mm

Accelerates a 2-kg copper mass to 2 km/s to collide with the asteroid surface, forming an artificial crater.



Mission's phases

03/12/2014
Launch

03/12/2015
Earth swing-by

27/06/2018
Approach and starting of remote-sensing analysis

21/09/2018
MINERVA-II-1A and MINERVA-II-1B rover release (altitude 60 m)

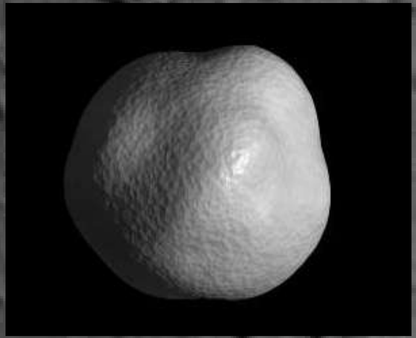
03/10/2018
MASCOT release (altitude 3 km)

25/10/2018
Release of target marker

- Collect samples from surface (**21/02/2019**)
- Creation of artificial crater (**05/04/2019**)
- Touchdown in the crater (**11/07/2019**)
- Release of MINERVA-II-2 (**03/10/2019**)

11/2019
Departure from Ryugu

6/12/2020
Return to Earth of 5g collected samples



Extension of the mission
2027- Flyby to 2001 CC21
2031- Rendezvous to 1998 KY26

Image taken from Rover 1A
September 27, 2018

Image taken from Rover 1A (during a hop)
September 22, 2018

23/09/2018 09:46 (JST)

Image taken from Rover 1B

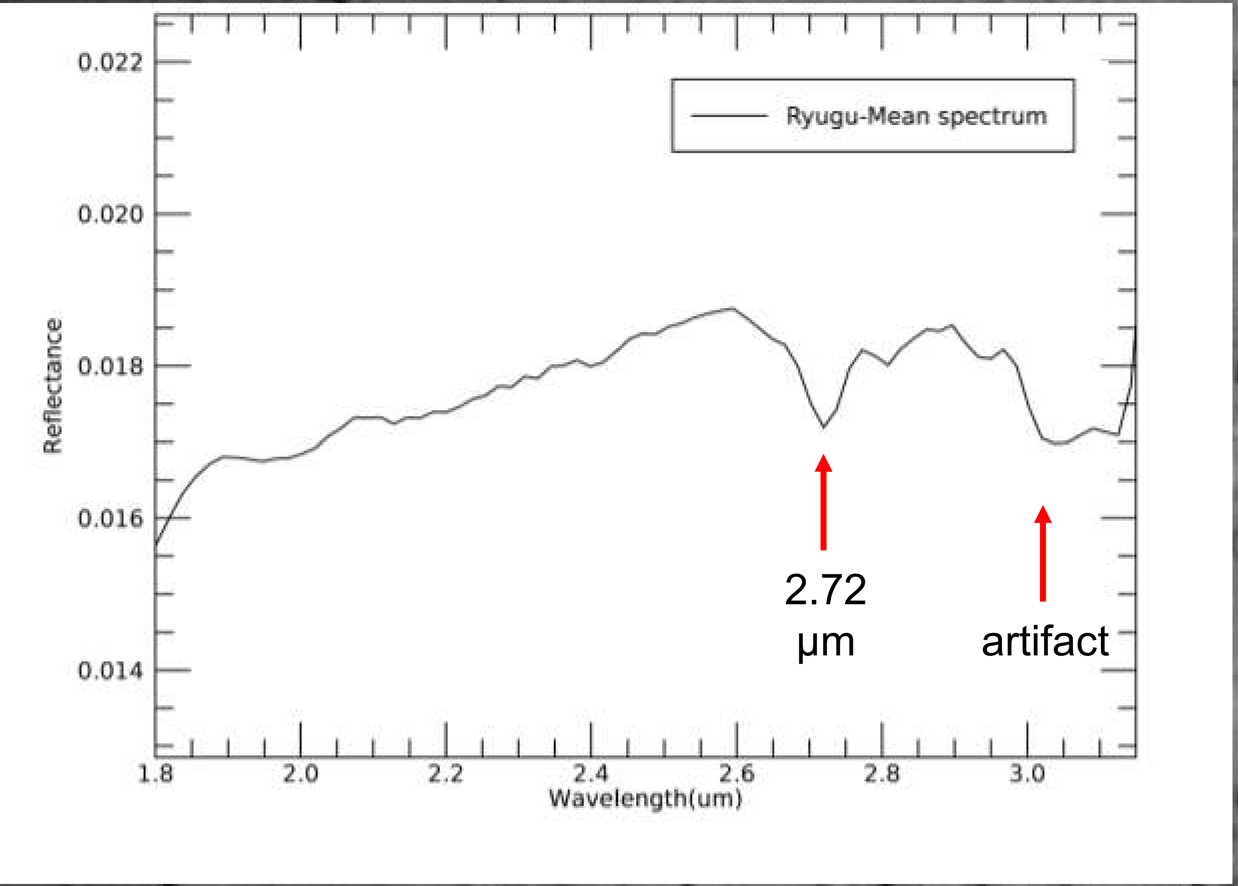
The surface is covered by impact craters and boulders with a size up to 160 m (Sugita+, 2019; Watanabe+,2019)

High bulk porosity, related to large boulder microporosity (Grott+,2020)

Rubble pile asteroid (Watanabe+,2019)

Image credit: JAXA

Mean reflectance spectrum of Ryugu acquired by NIRS3 spectrometer onboard Hayabusa2



- ➢ Low reflectance: 1.7% @2.0 µm (carbon, magnetite or products of shock-induced metamorphism, i.e. dark glassy component)
- ➢ 2.72 µm band: OH symmetric stretch in Mg-rich phyllosilicates
- ➢ Positive (red) spectral slope

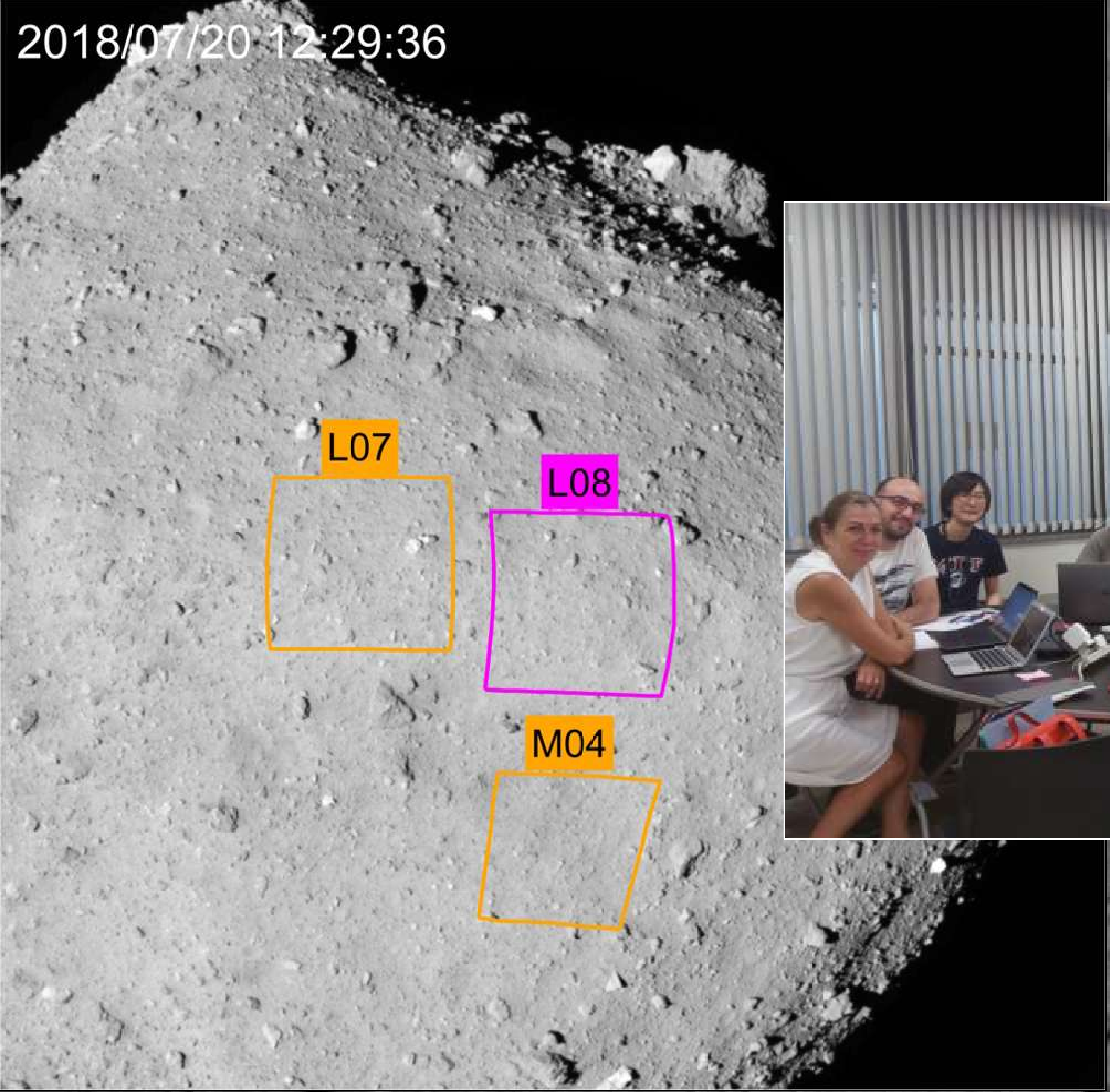
(Kitazato+,2019)

Spectrally similar to thermally metamorphosed CI chondrites or shocked CM chondrites (Kitazato+, 2019): the fragments that formed Ryugu probably experienced thermal metamorphism as a consequence of the collisional event that fragmented the parent body (Watanabe+,2019), producing darkening and
and the dehydration/dehydroxylation of hydrated minerals (Kitazato+, 2019).

Ryugu experienced aqueous alteration prior to any dehydration process, strongly supporting the occurrence of hydrated minerals such as phyllosilicates in the Ryugu's regolith (Hamm+,. 2022).

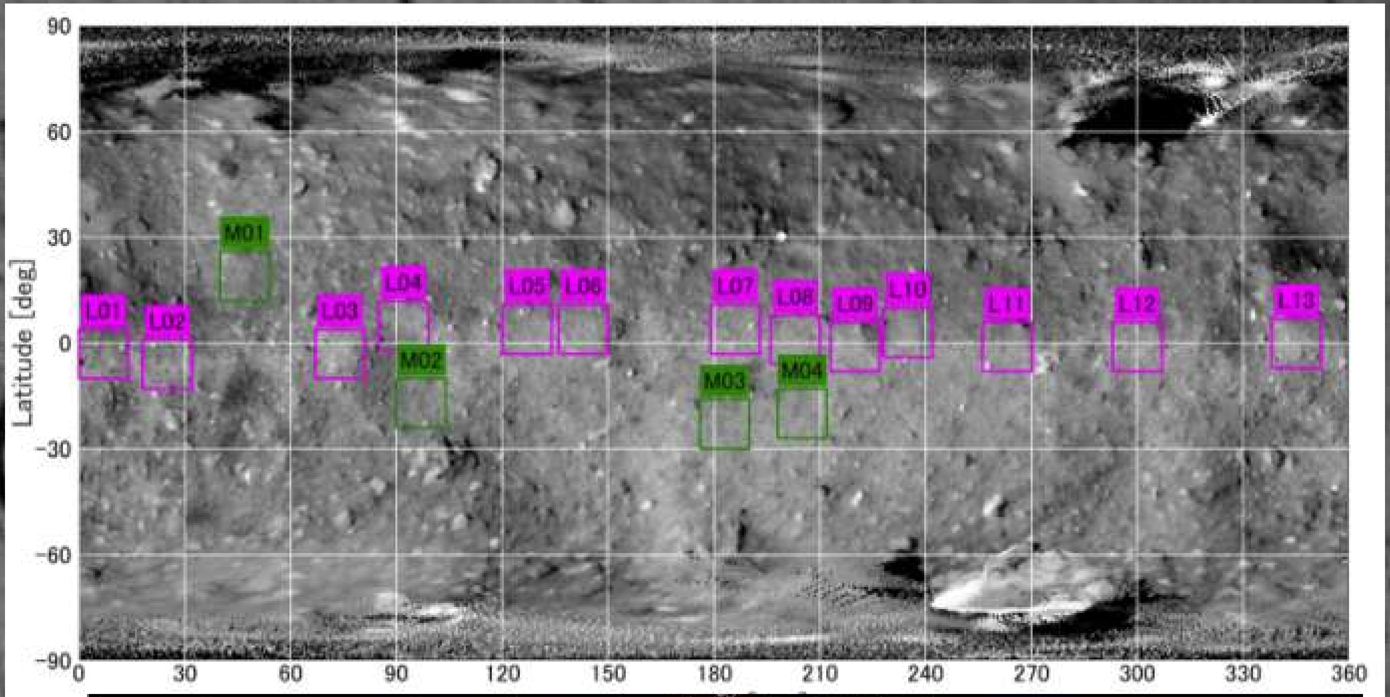
Then, the analysis of collected samples suggests that Ryugu is more similar to CI chondrites, but characterized by a lower albedo, higher porosity, and more fragile properties (Yada et al. 2022).

Selection of the site for TD1 at JAXA (Sagamihara, Japan)

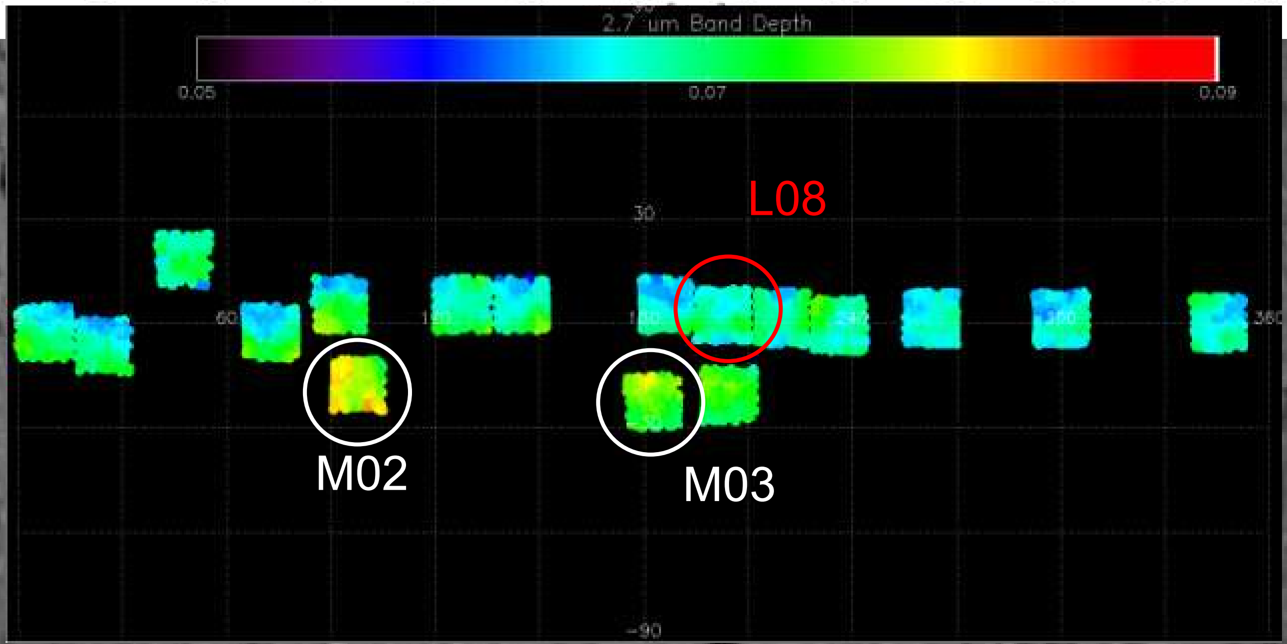


Support for the landing and sampling site selection activity

Proposed sites for Hayabusa2 landing based on engineering criteria

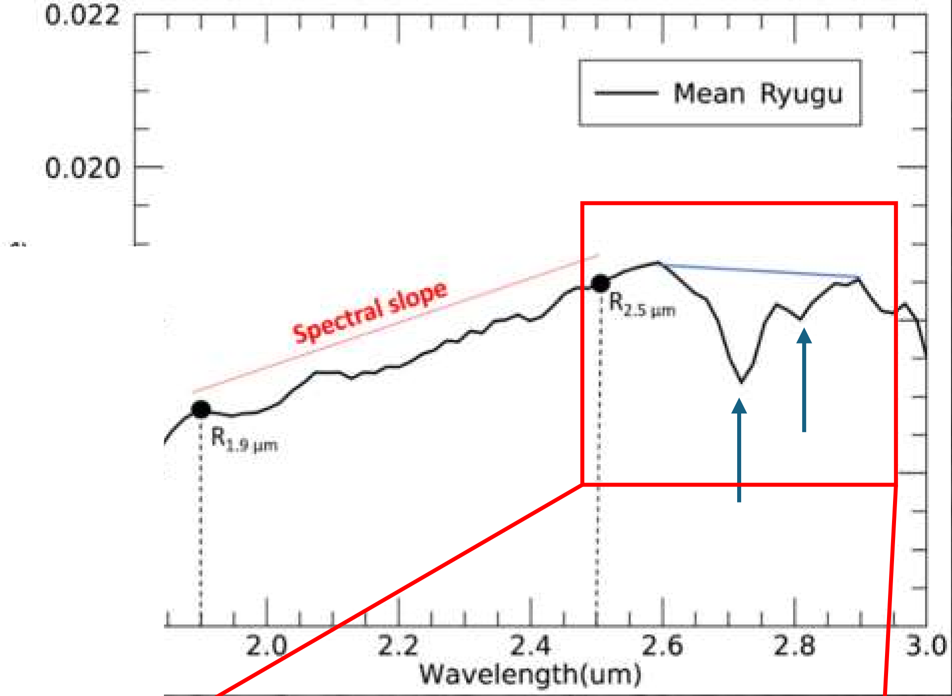


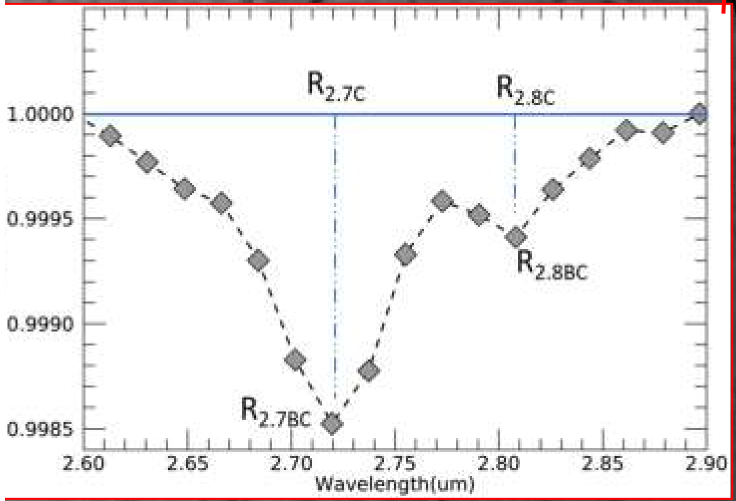
Selected sites with deeper 2.7 um band, i.e. richer in hydrated minerals



Spectral parameters for the mineralogical investigation

NIRS3 spectral data have been photometrically and thermally corrected, obtaining the following mean spectrum





- Reflectance at 1.9 µm

information about composition/grain size

- 1.9-2.5 µm spectral slope: $\frac{R_{2.5}-R_{1.9}}{2.5-1.9} \cdot \frac{1}{R_{1.9}}$

Information about space weathering effects or variation in composition/grain size

Absorption bands at 2.72 µm (OH in Mg-rich phyllosilicates) and 2.8 µm (probably OH in Fe-rich phyllosilicates)

- Band Center (BC): wavelength with the minimum reflectance value in the isolated absorption band

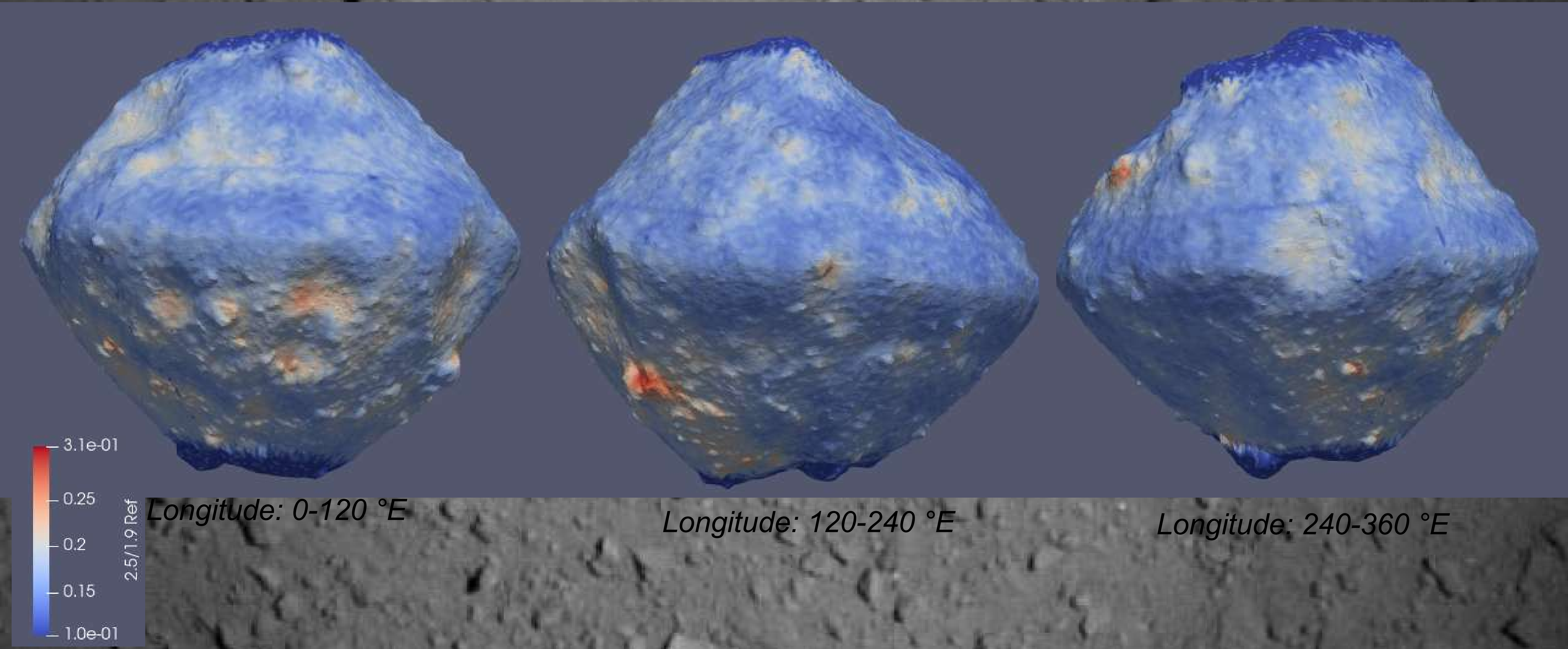
indicative of the mineral's specie responsible of the spectral feature

- Band Depth (BD): $1-\frac{R_{BC}}{Rc}$

qualitative information about the abundace of mineral

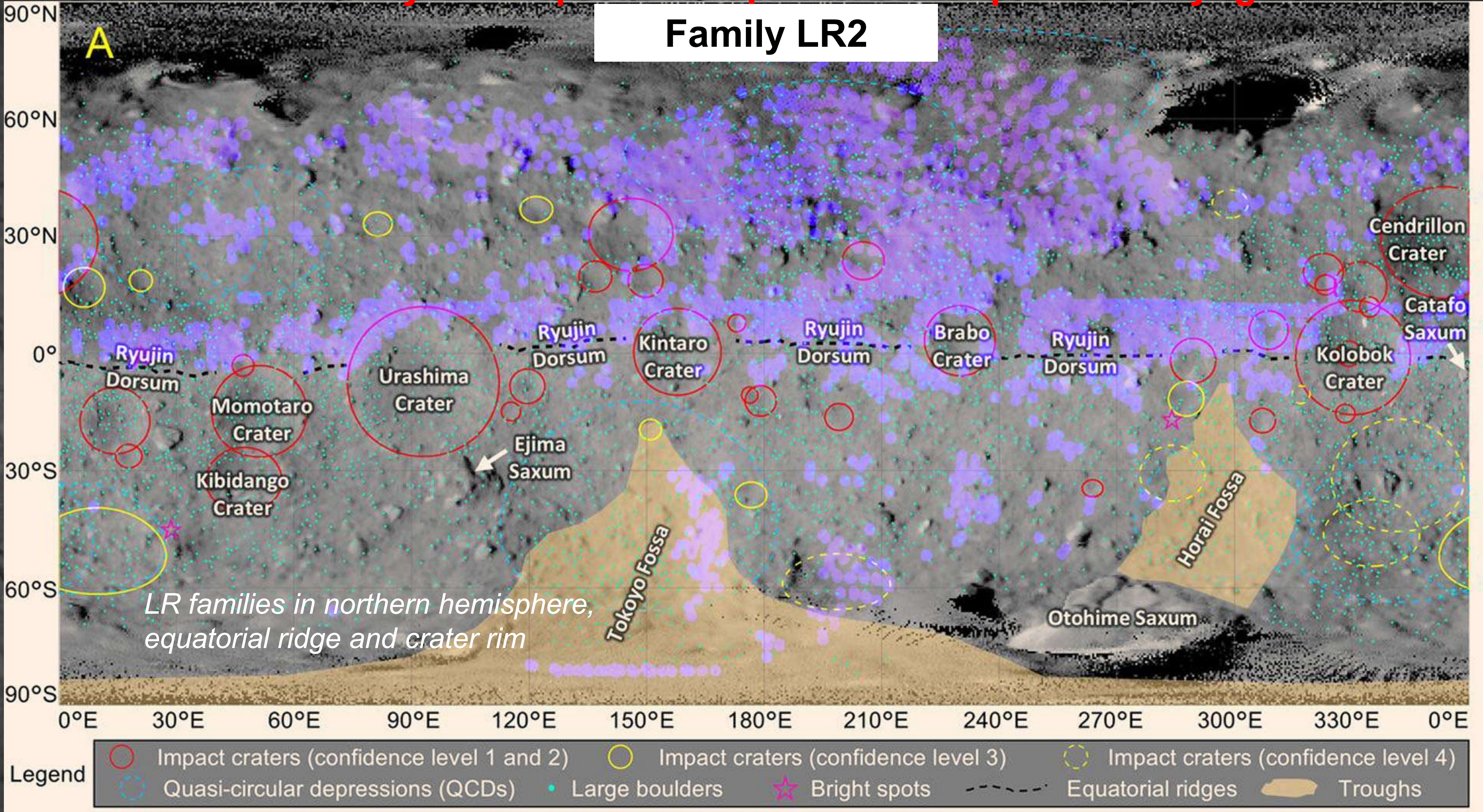
Analysis of spectral slope in NIRS3 spectra of Ryugu

Map of spectral slope on Ryugu shape model



Analysis of spectral slope in NIRS3 spectra of Ryugu

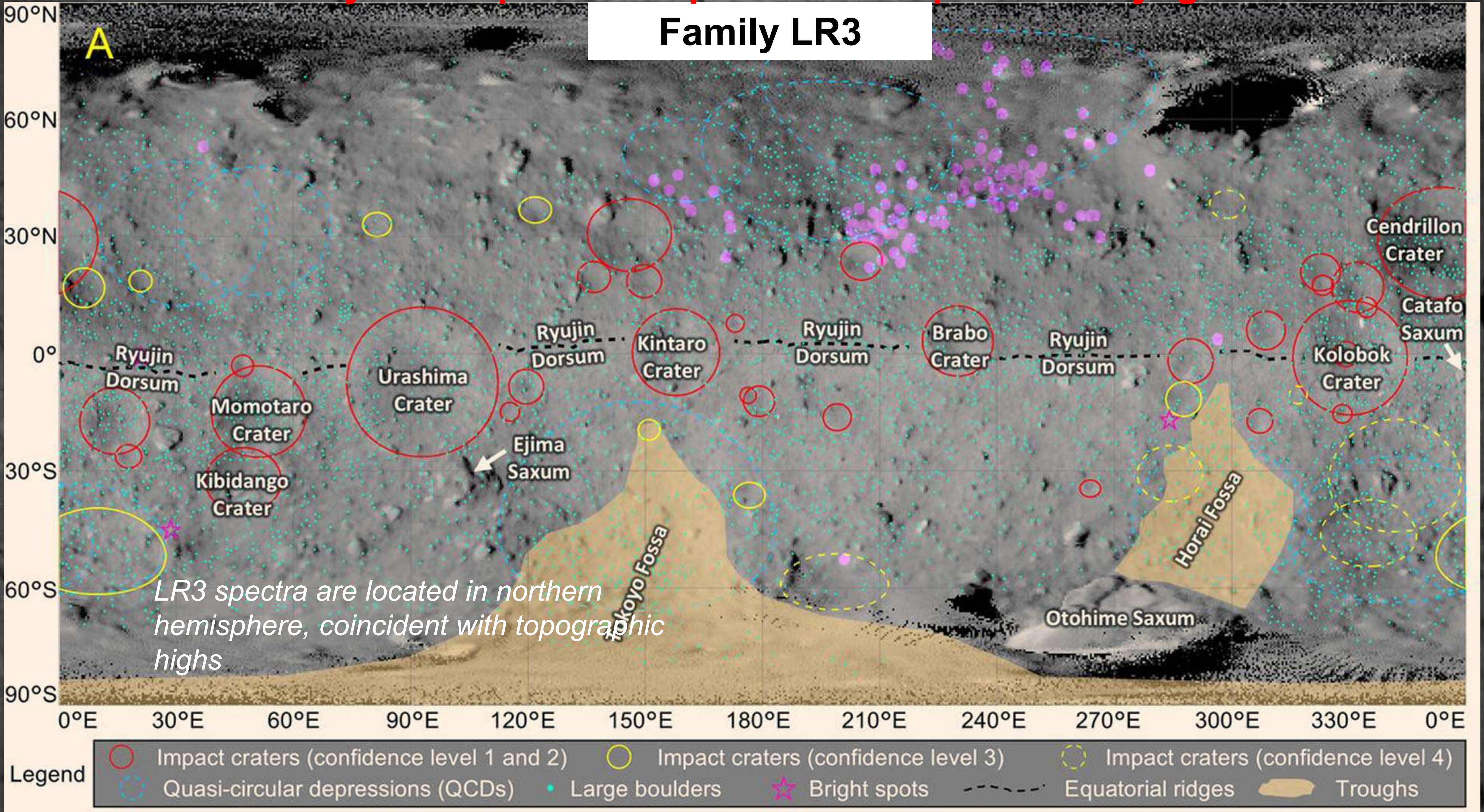
Family LR2



LR families in northern hemisphere, equatorial ridge and crater rim

Analysis of spectral slope in NIRS3 spectra of Ryugu

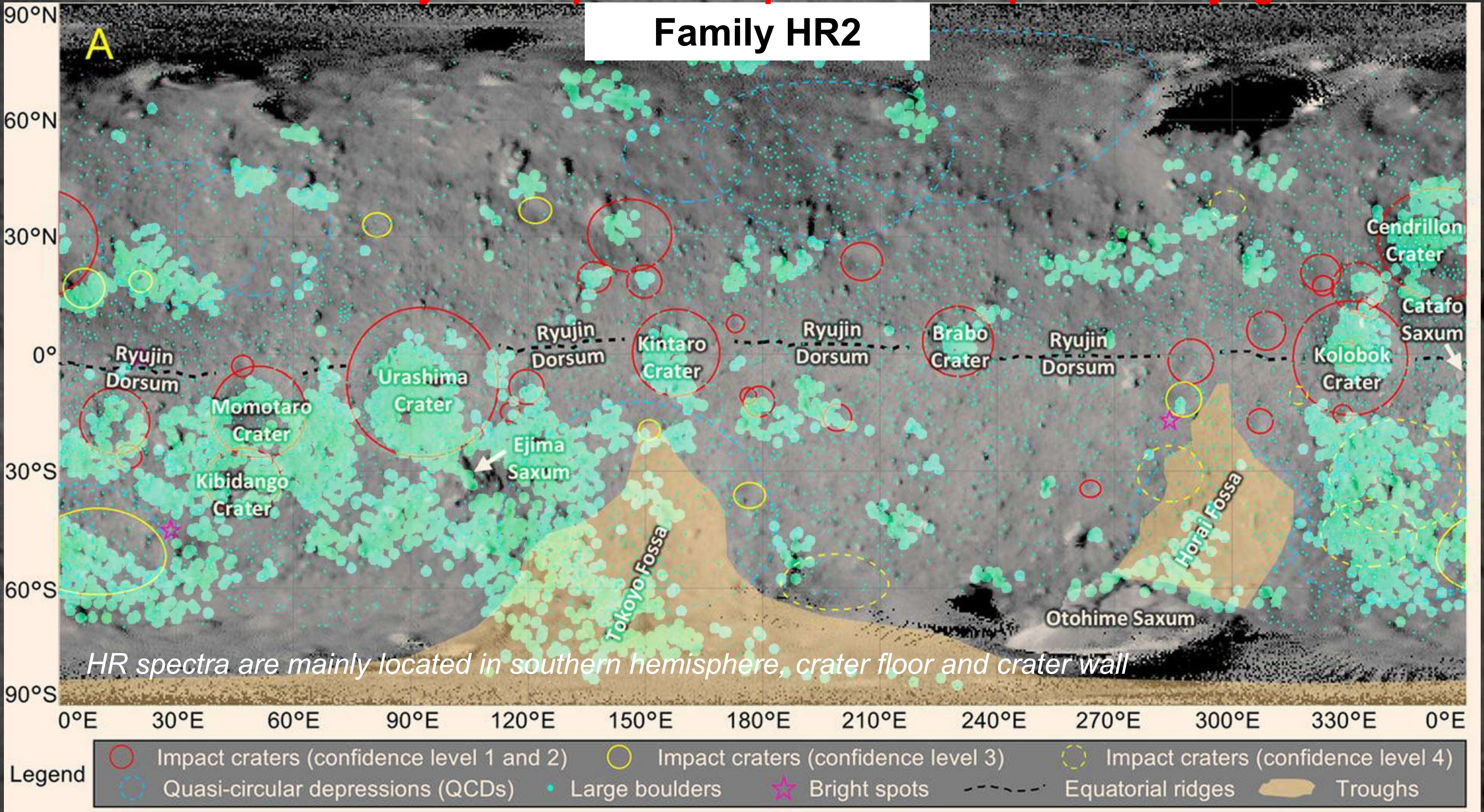
Family LR3



LR3 spectra are located in northern hemisphere, coincident with topographic highs

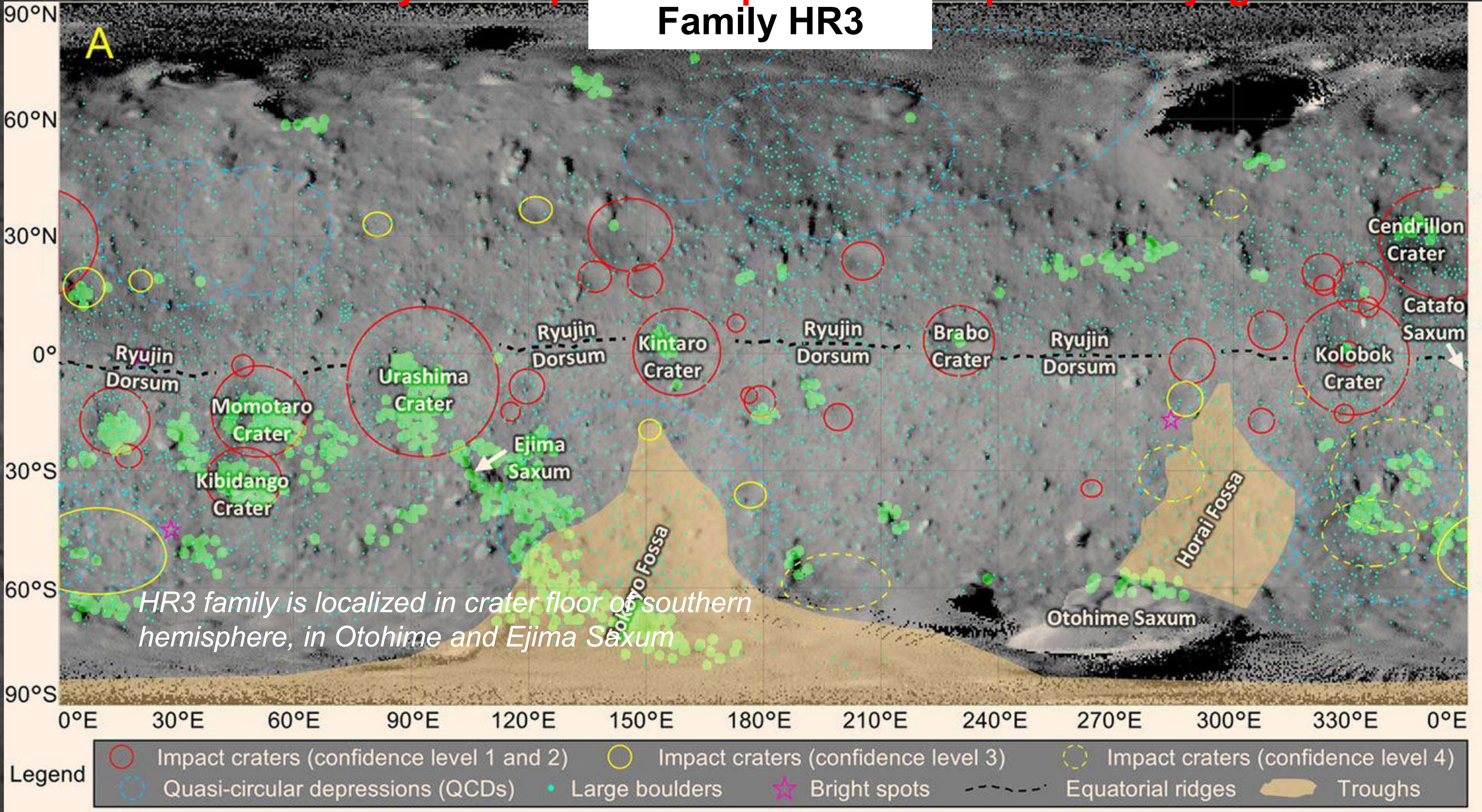
Analysis of spectral slope in NIRS3 spectra of Ryugu

Family HR2



Analysis of spectral slope in NIRS3 spectra of Ryugu

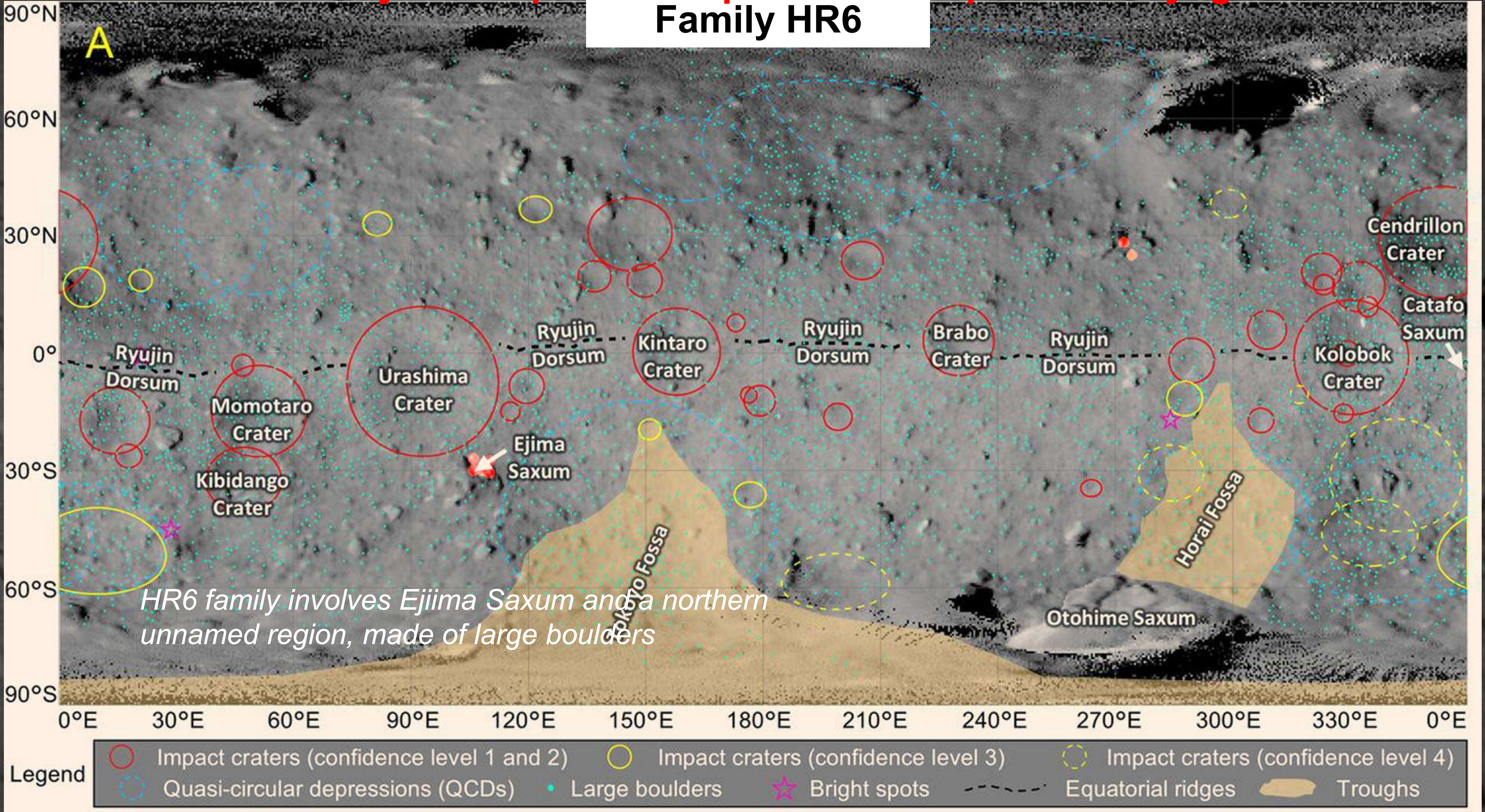
Family HR3



HR3 family is localized in crater floor of southern hemisphere, in Otohime and Ejima Saxum

Analysis of spectral slope in NIRS3 spectra of Ryugu

Family HR6



HR6 family involves Ejiima Saxum and a northern unnamed region, made of large boulders

Discussions

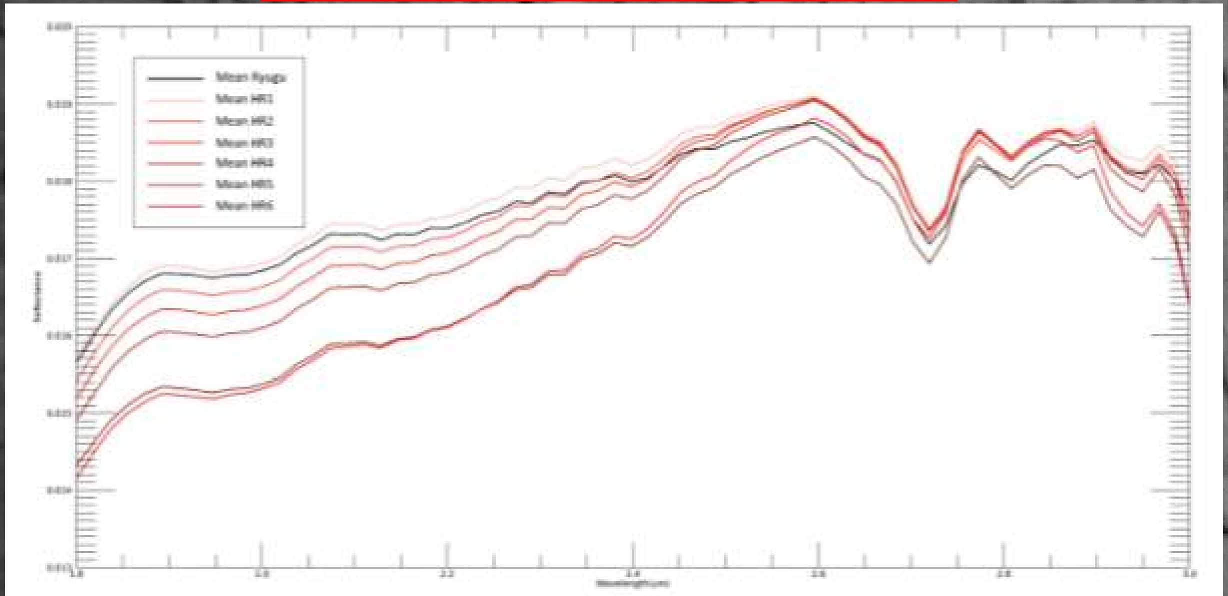
High-Red-sloped families

Areas with increasing redder slope

Darkening in reflectance

Weakening of OH band

Southern hemisphere
Crater floor
Crater wall
Ejiima Saxum
Otohime Saxum



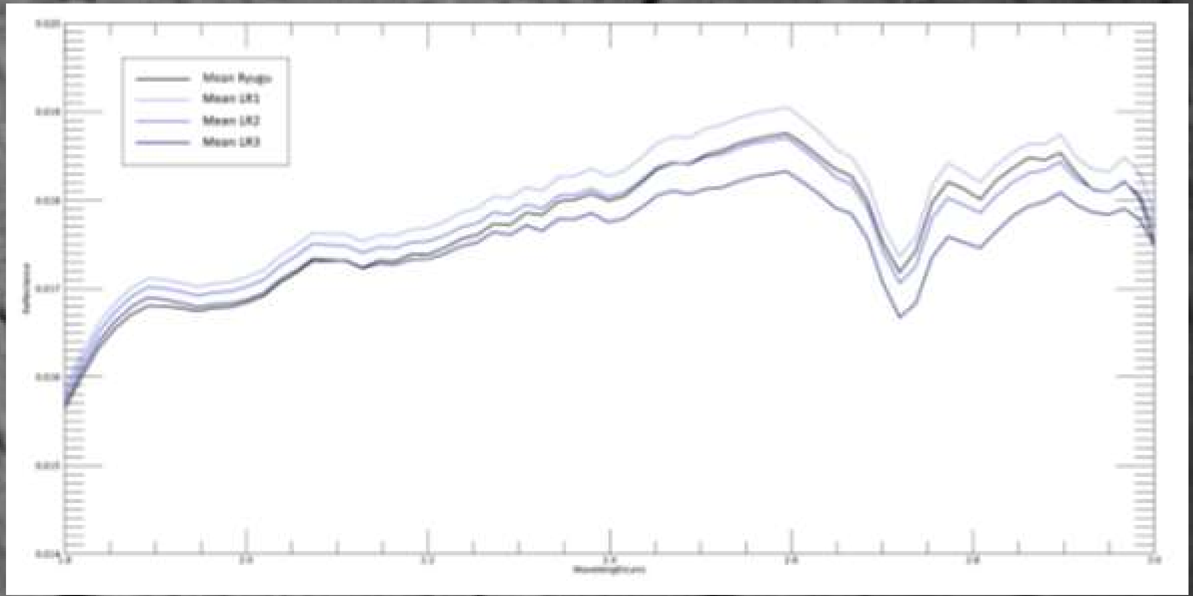
Low-Red-sloped families

Areas with flatter slope

Uniform reflectance and similar to Mean Ryugu

Deepening of OH ban

Northern hemisphere
Equatorial ridge
Crater rim



Possible explanation of slope's families on Ryugu surface

To explain the spectral variations observed on Ryugu surface, three processes need to be taken into account:

1) the **thermal metamorphism** experienced by the material composing Ryugu for the fragmentation of parent body;
2) the **impacts** on the surface during the permanence of Ryugu in the Main-Belt, which produced larger craters;
3) the **solar wind irradiation** on the surface during its actual permanence in the Near-Earth orbit, lasting at least from 8 Myr.

Laboratory experiments

1) **Thermal heating** on CM2 Murchison powder samples showed **a weakening of hydration band** at higher heating temperatures, with **a bluing** and a **spectral darkening** (up to 600 °C) (*Hiroi et al., 1996*)
2) **Laser irradiation experiments** on chips of CM2 meteorite produced a **darkening and spectral bluing** (*Thompson et al., 2019*). **The fragmentation of regolith could infer a spectral reddening and brightening** (*Cloutis et al., 2018*)
3) **Ion irradiation experiments** on a section of CM2 Murchison detected a **spectral reddening and darkening**, in addition to a **weakening and narrowing of OH band** (*Keller et al., 2015*)

Experiment0	Sample	Space Weathering Effects			
		Reflectance	Slope	Intensity of OH-band	Width of OH-band
Heating	CM2 Murchison	– (up to 600°C)	–	–	
	CM-like material				–
Laser irradiation	CM2 Murchison	–	–		
Ion Irradiation	CM2 Murchison	–	+	–	–

Discussions

Thermal metamorphism on fragments of Ryugu's parent body: weak OH band, spectral darkening and bluing
Solar wind irradiation: spectral reddening, darkening and weakening of OH band

Mean surface of Ryugu, in particular the **HR1, LR1 and LR2** families (equatorial ridge, crater rims)
The **LR3** family corresponds to topographic highs (Sugita+,2019), which probably exposed fresher materials that experienced less hydration: it is the brightest area with the deepest OH bands and could represent a more hydrated and less altered area

Thermal metamorphism on fragments of Ryugu's parent body: weak OH band, spectral darkening and bluing
Meteoritic impacts: darkening and spectral flattening
Fragmentation of regolith: spectral reddening and brightening
Solar wind irradiation: spectral reddening, darkening and weakening of OH band

HR2, HR3, HR4 and HR5 families (geological features related to craters, e.g. walls and floors)

Thermal metamorphism on fragments of Ryugu's parent body: weak OH band, spectral darkening and bluing
Solar wind irradiation: spectral reddening, darkening and weakening of OH band
Fine regolith covering the boulder (Sujita+,2019): strong spectral reddening

HR6 family-Ejima Saxum

TD1
22 February 2019

Darkening of the TD1 area

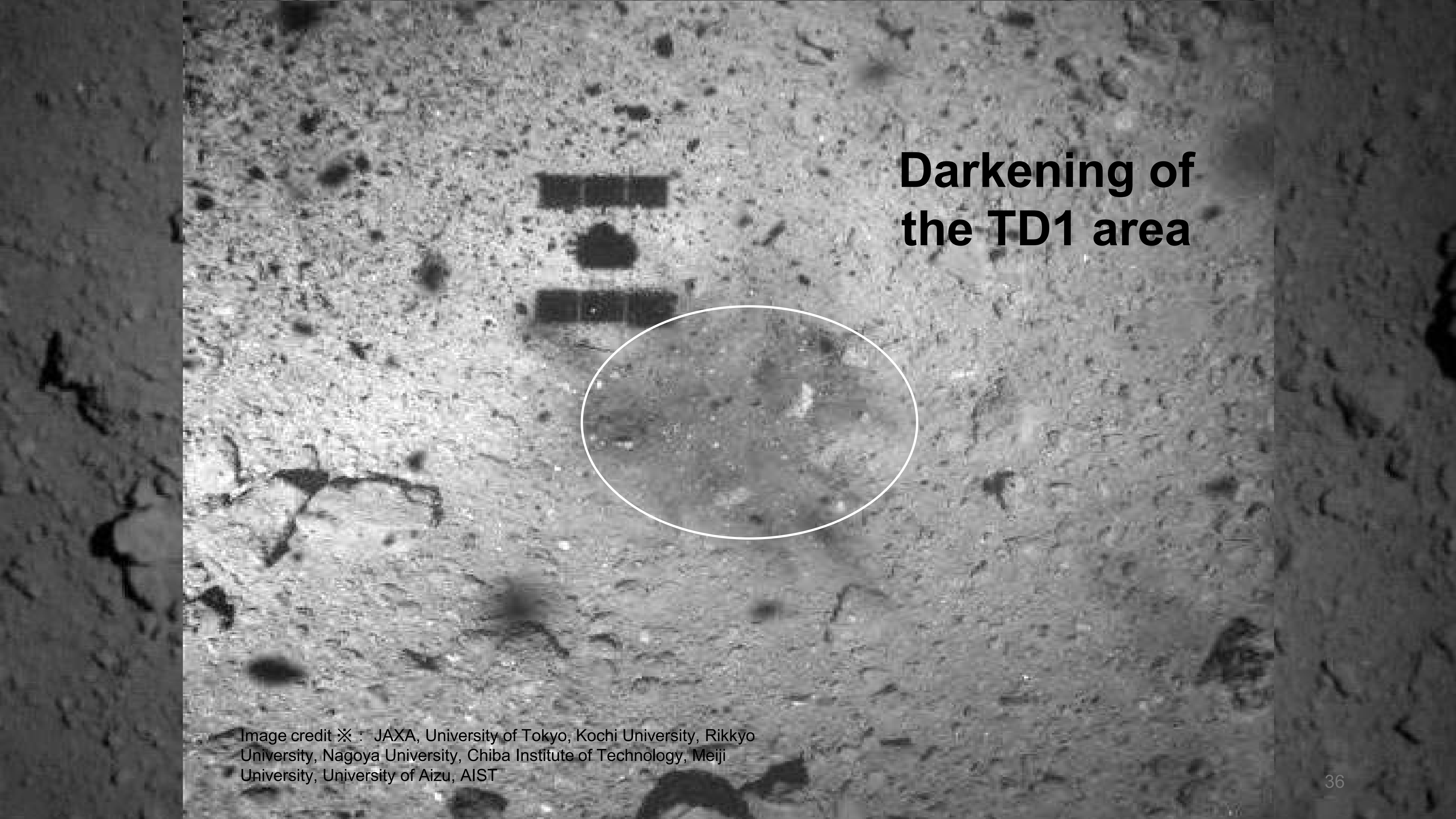
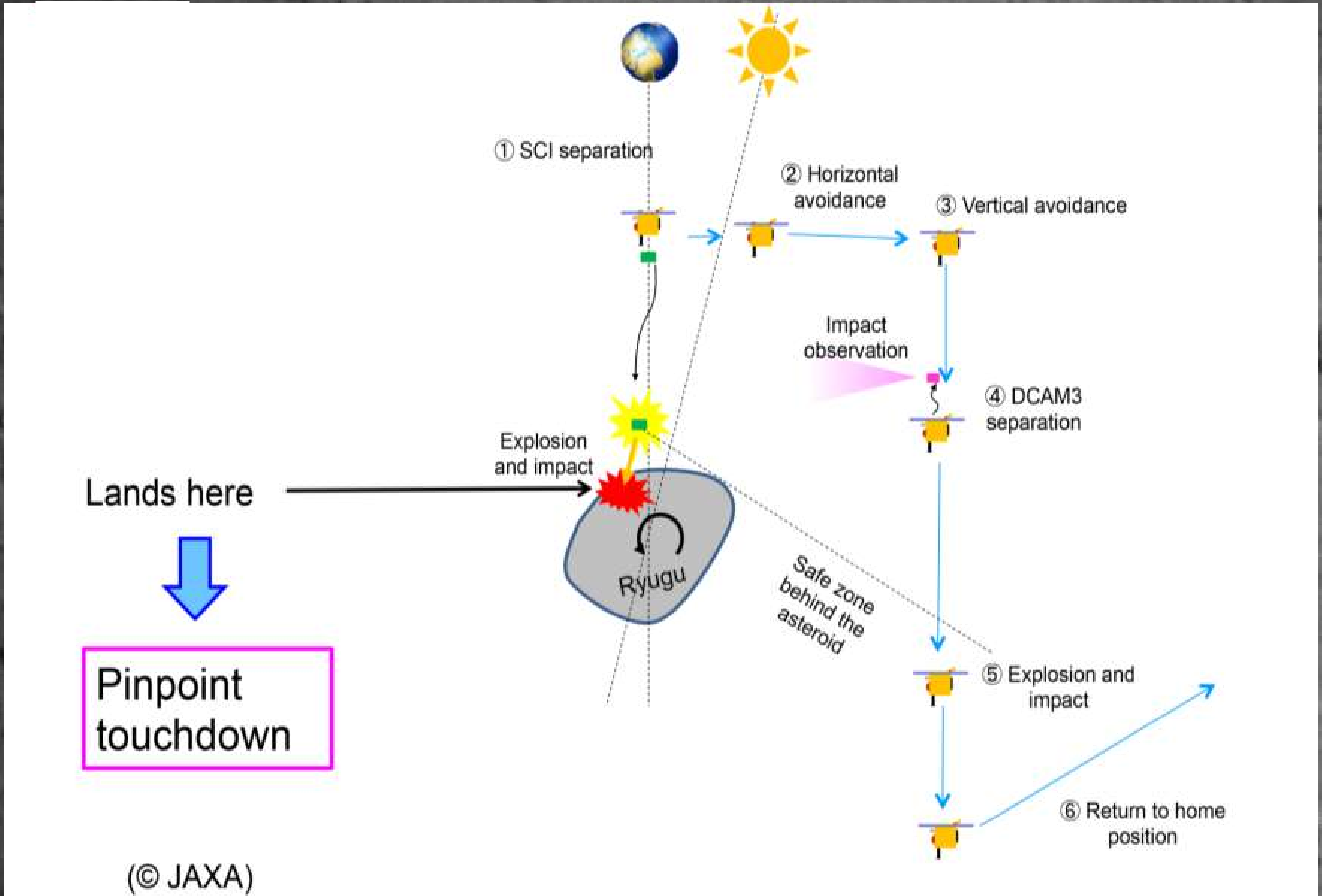
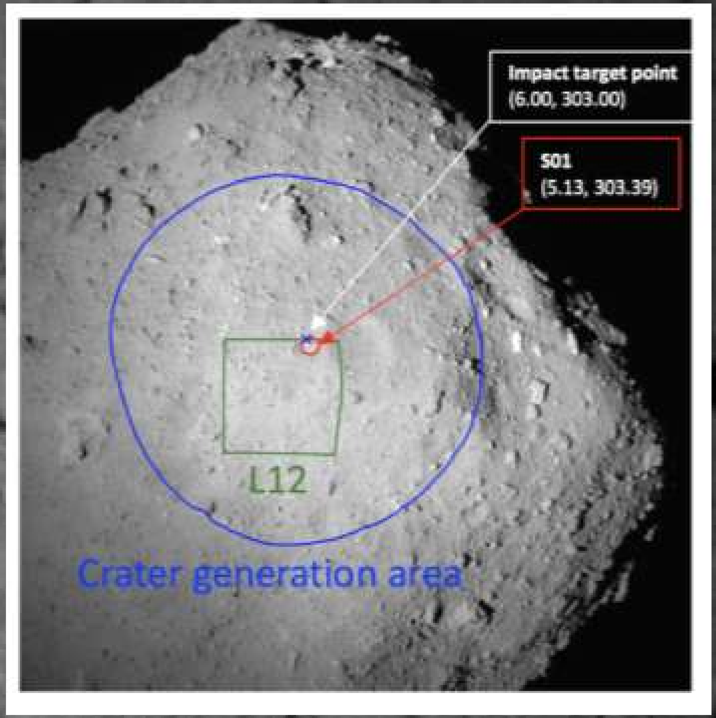


Image credit ※： JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu, AIST

Creation of artificial crater in the S01 site





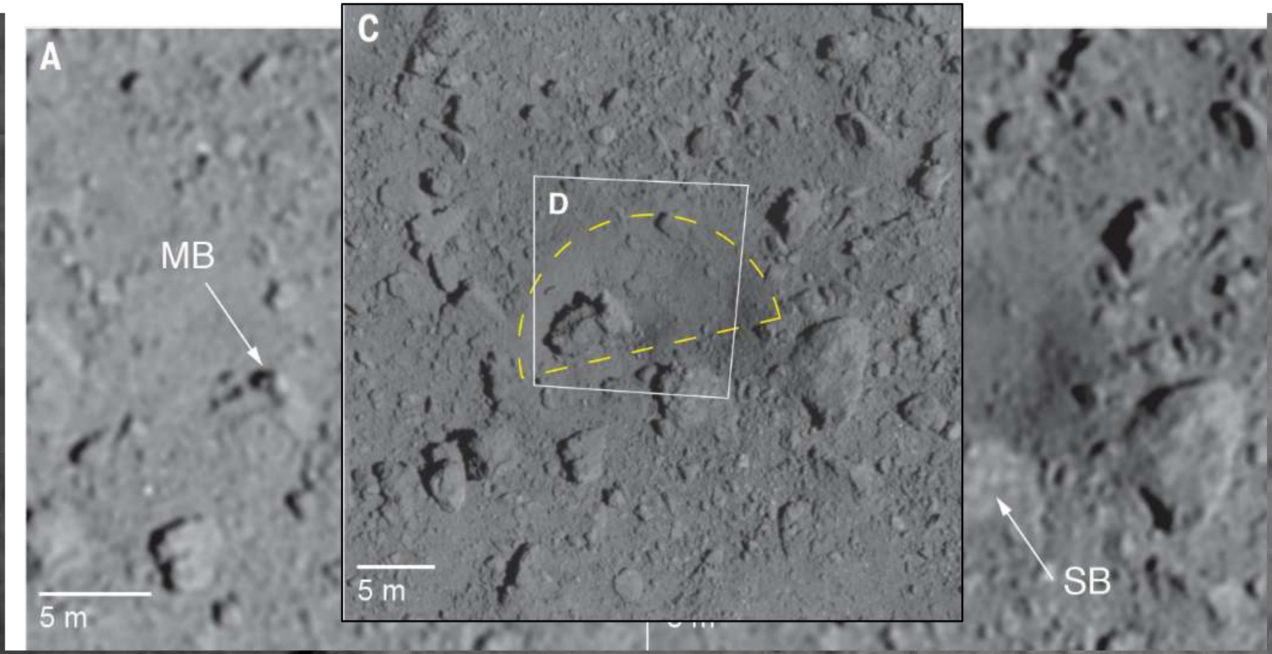
SCI Operation and TD2

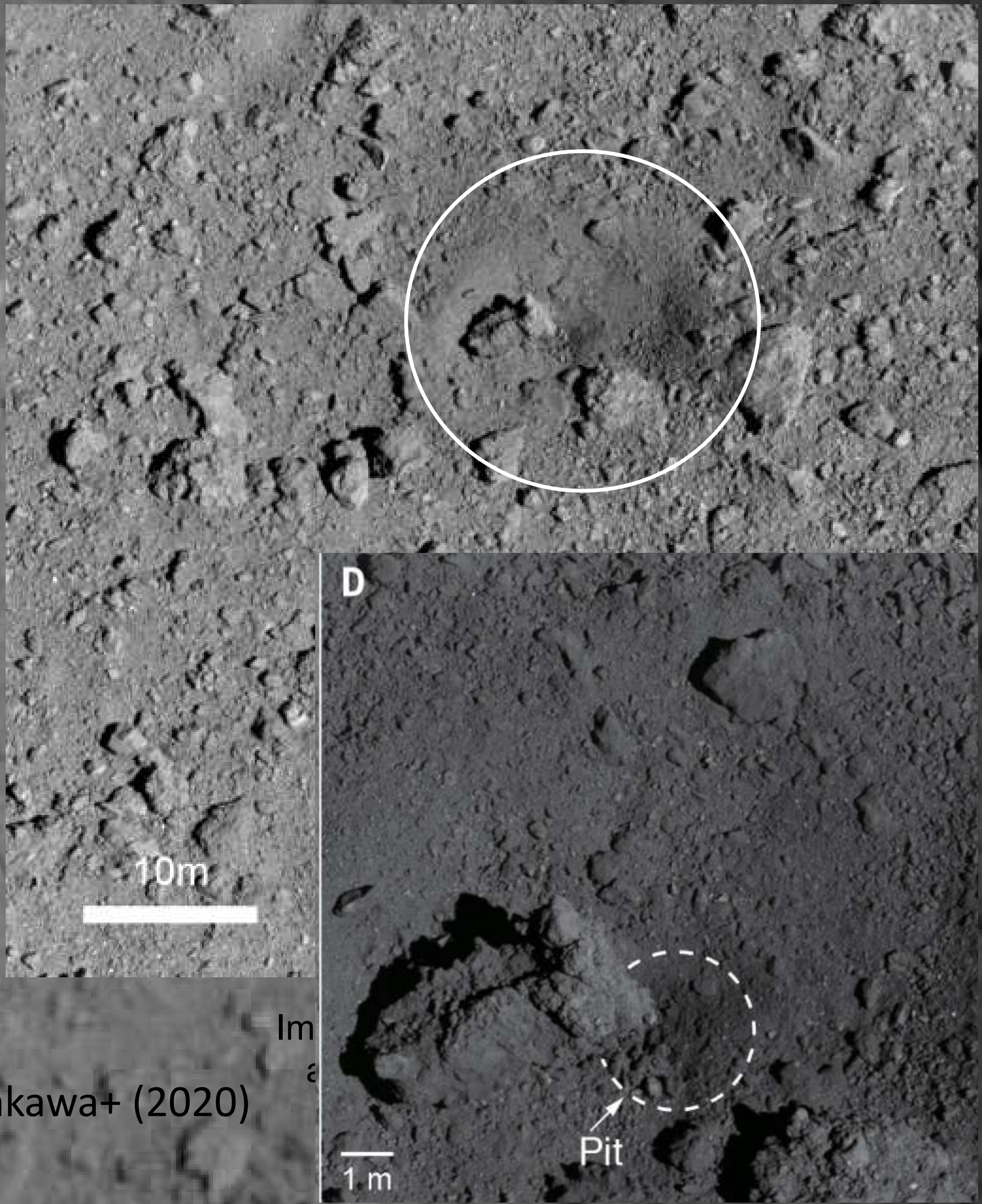
TD2
11 July 2019

Creation of artificial crater in the S01 site

«Omusubi-Kororin crater» (7.9°N, 301.3°E)

- Angle of impact: 60°
- Rim-to-rim diameter: 17.6±0.7 m
- Pit in the vicinity of the impact point (3 m diameter, 0.6 m deep), depth 2.7 m from the top of the rim
- Subsurface material ejected from 1 m depth
- Mobile Block (MB) of 5 m was excavated and moved of 3 m north-west from the initial position
- Stable Block (SB) barely moved after the impact, part of a larger block buried in the subsurface and halted the crater growth toward south-east

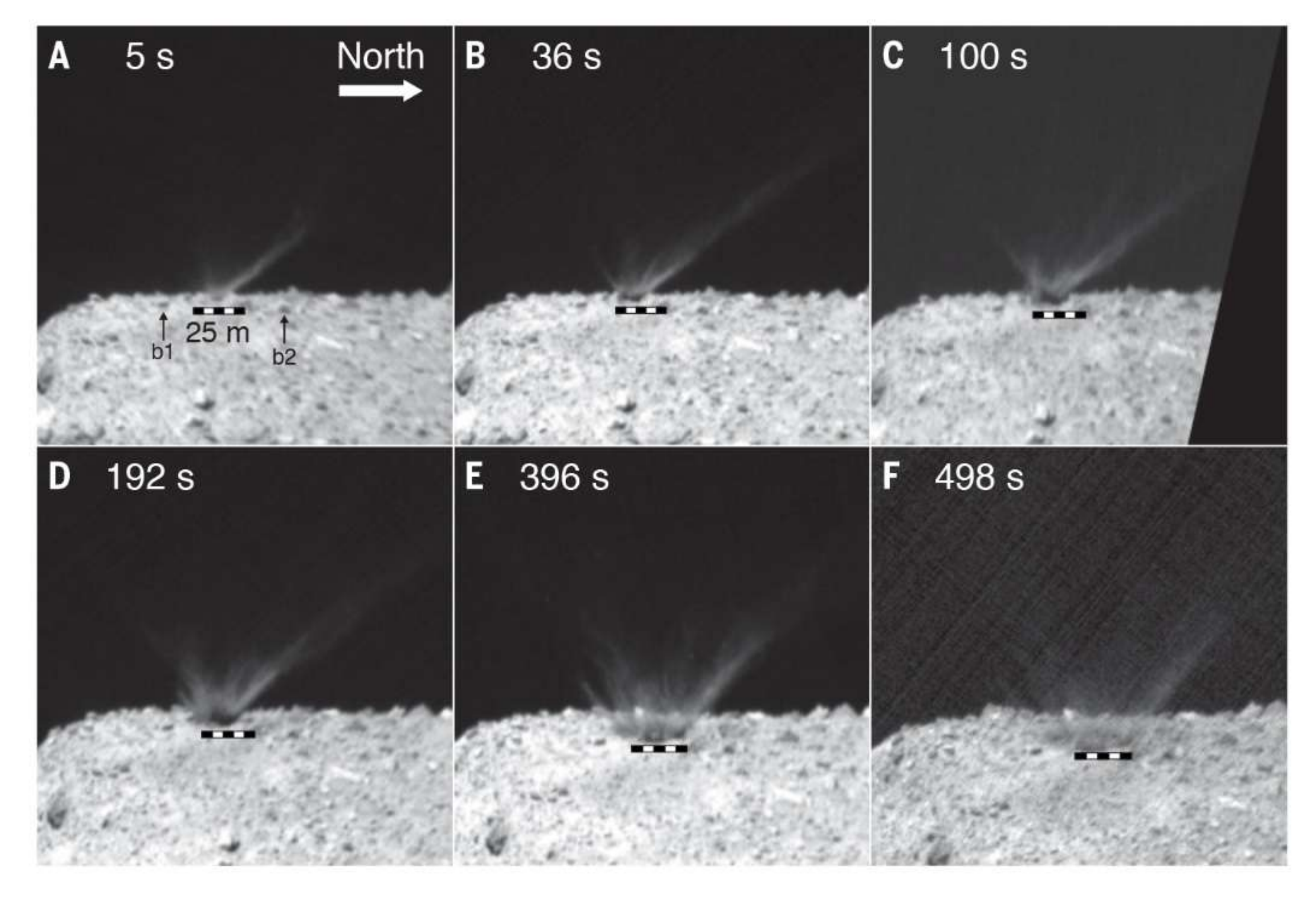




Arakawa+ (2020)

Creation of artificial crater in the S01 site

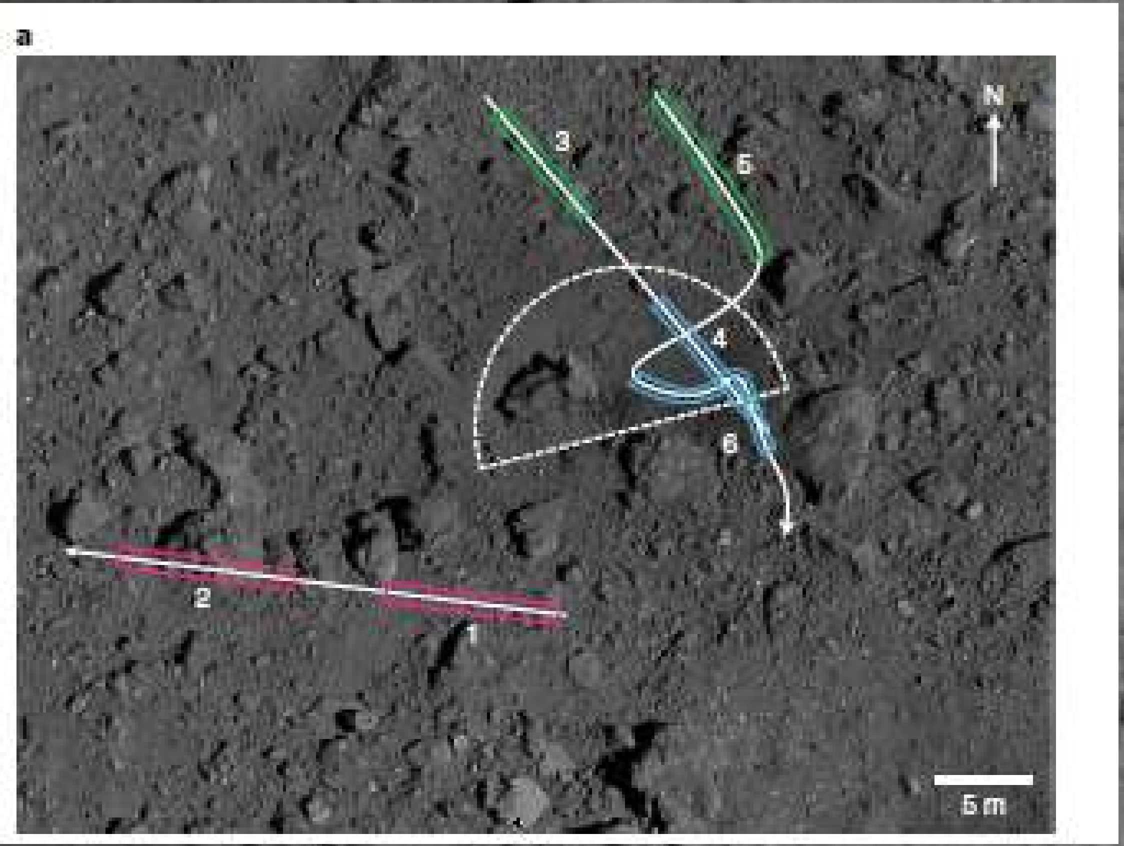
Ejecta from Ryugu after the SCI operation, captured by the DCAM3

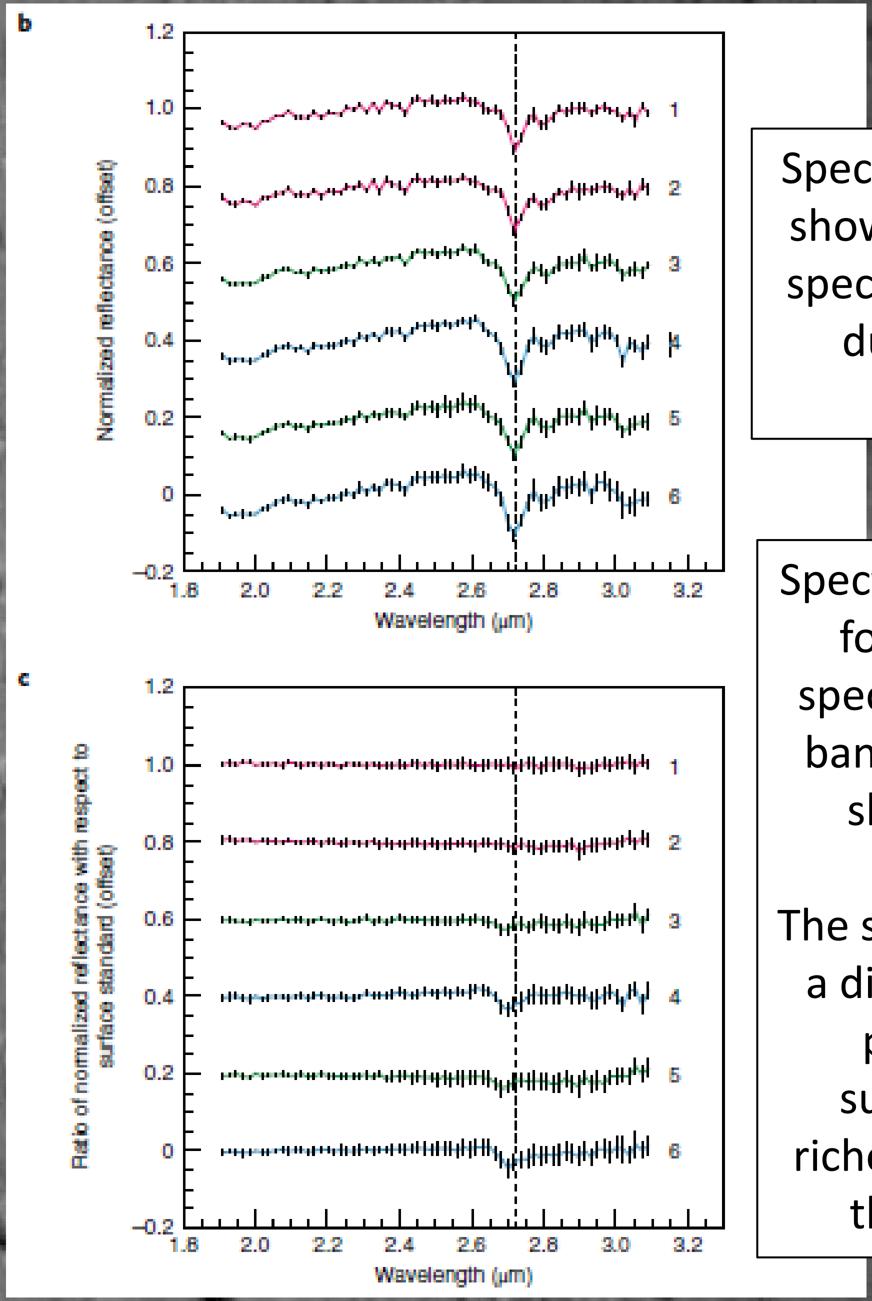


Ejecta from Ryugu emerged with an angle of 40° with an asymmetric distribution, present in the northern part and absent in the southern one.

Arakawa+ (2020)

Spectral analysis of Omusubi-Kororin crater





Kitazato+ (2020)

Spectra of ejecta-rich areas show the 2.72 μm band as spectra of the surface area due to OH in Mg-rich phyllosilicates

Spectra of SCI crater ratioed for a surface standard spectrum show a stronger band, also shifted toward shorter wavelengths.

The shift could be related to a different Mg/Fe ratio in phyllosilicates, thus subsurface material is richer in Mg phyllosilicates than the surface one

Spectral analysis of Omusubi-Kororin crater

Conclusions

Post-crater areas have stronger 2.72 and 2.8 μm bands

→ The subsurface material could be more hydrated (richer in OH material) than the surface one or made by finer size of grains

Post-crater areas are darker and redder

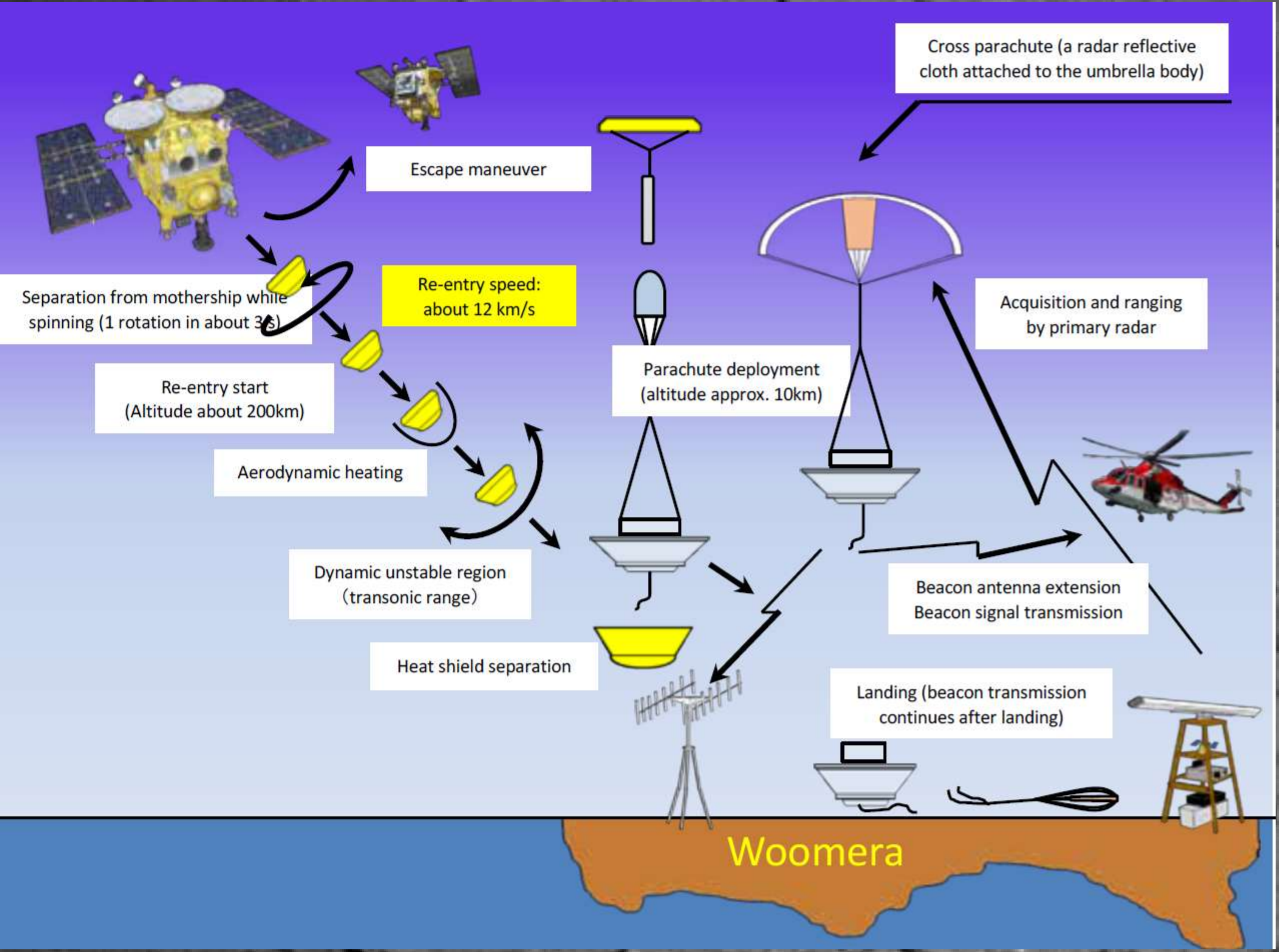
→ Exposition of the subsurface fine-sized darker material, in accordance with Arakawa+(2020) and Morota+(2020) and supported by previous laboratory experiments (e.g. Cloutis+2011)

Variation of spectral parameter in the southern part of the crater

→ Ejecta moved not only in norther direction (as in Arakawa+,2020) but also in the southern one, reaching a distance of 20 m from the impact point

Published in MNRAS: Galiano+(2022)

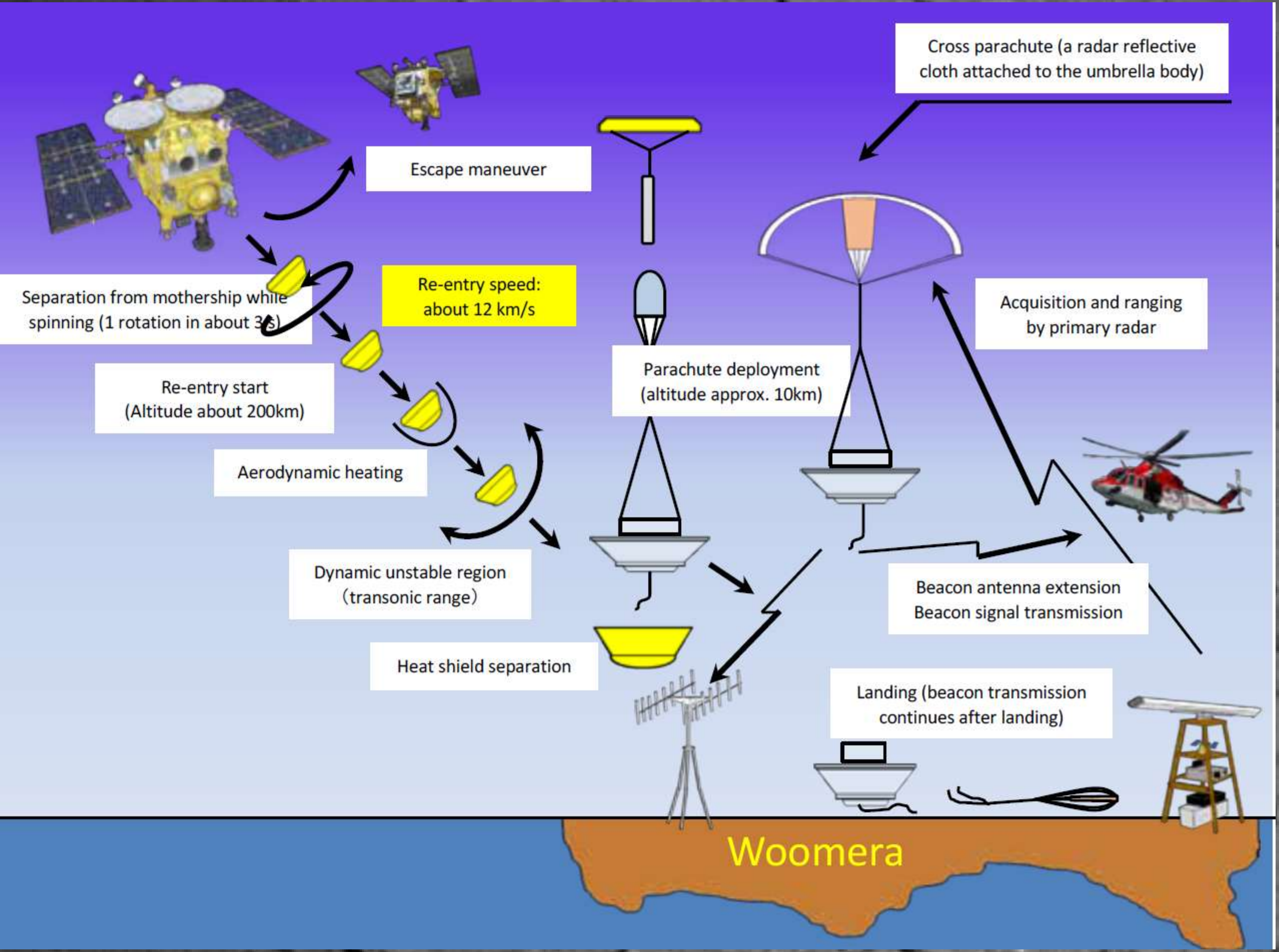
Capsule Recovery



Capsule separation:

As the spacecraft approaches the Earth, the ion engines are used to adjust the orbit to one that just passes by the side of the planet. During the final Earth approach, a total of five orbit corrections adjust the orbit of the spacecraft towards Australia. Then about 12 hours before re-entry, the capsule is separated. So one hour after capsule separation, the final TCM-5 is performed to put the spacecraft back into an orbit that passes by the side of the Earth. The capsule will meanwhile re-enter the atmosphere, and land in the Woomera Prohibited Area in Australia.

Capsule Recovery



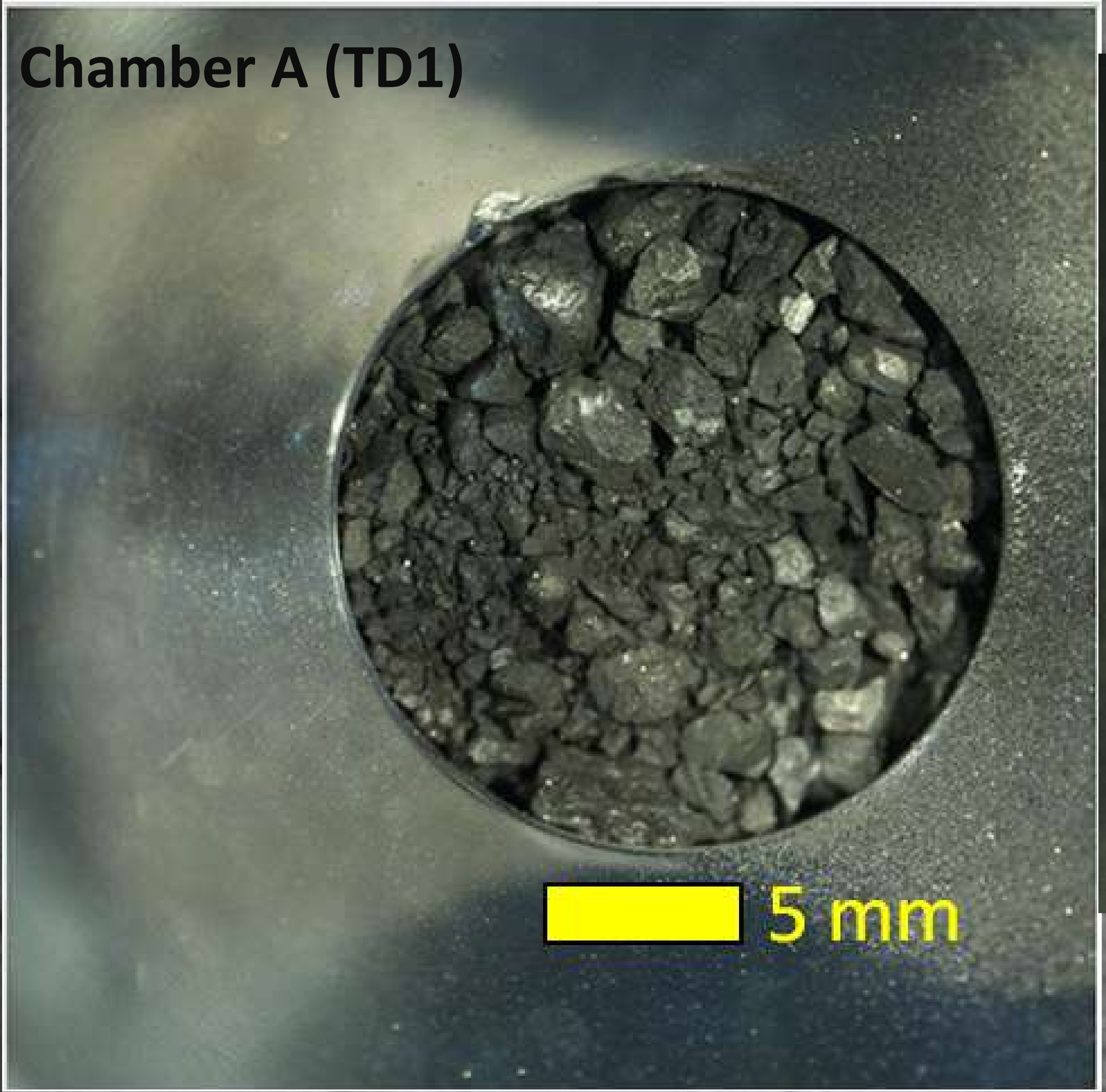
Capsule re-entry:

The capsule is accelerated by the Earth's gravity and re-enters the Earth's atmosphere at a speed of 12 km/s. During re-entry, the surface of the capsule becomes extremely hot, shining brightly as it reaches temperatures of about 3000°C. To protect the inside of the capsule from the heat, the outside of the capsule is encased in a heat resistant material (the heat shield), which keeps the inside temperature below 80°C. At an altitude of about 10km, the front and rear heat shields are separated. A parachute attached to the main body that contains the sample is deployed, and the beacon transmitting antenna is exposed. The capsule then slowly descends and lands, while transmitting the beacon signal.

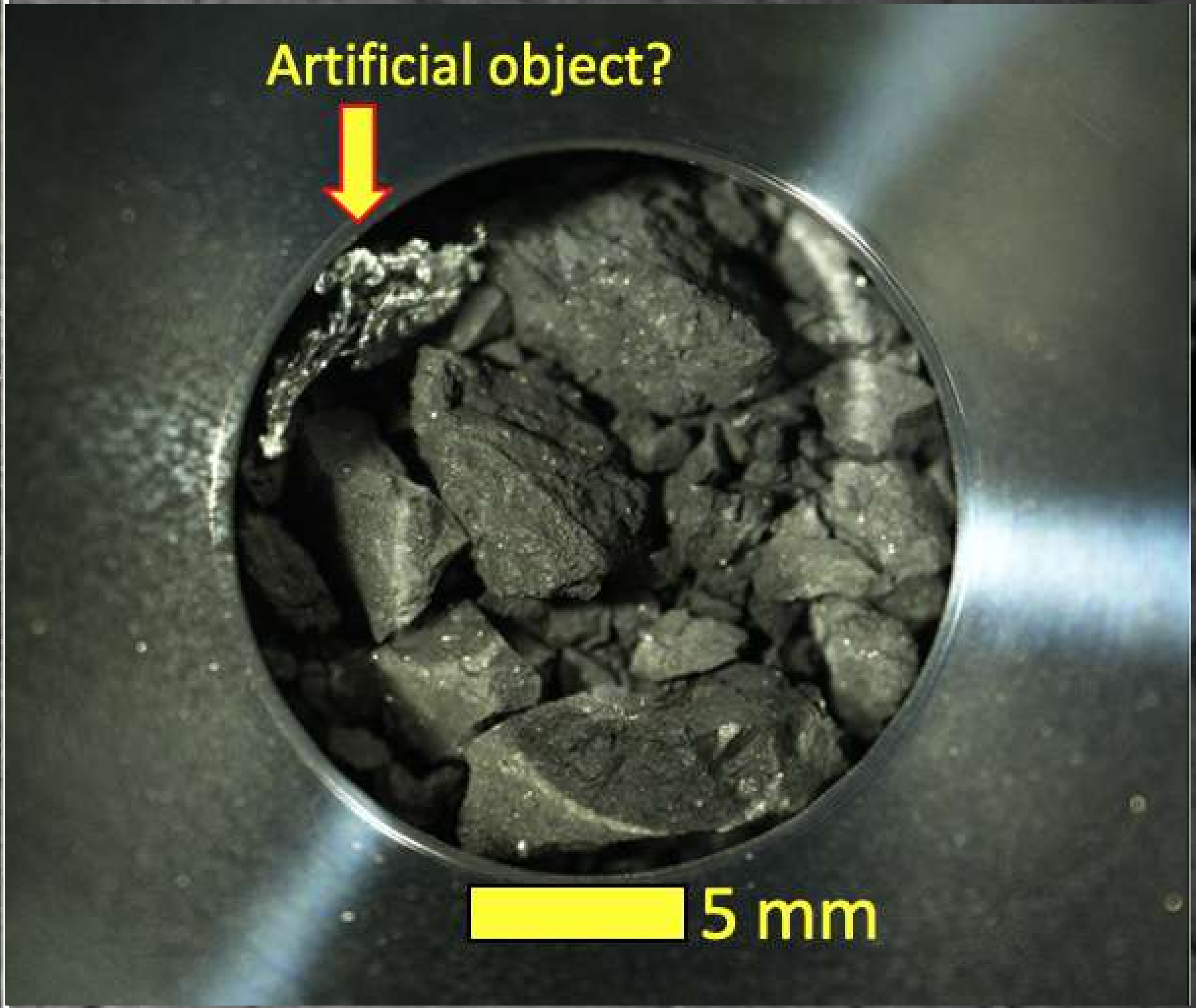
Capsule Recovery
6 December 2020

Capsule fireball seen from Coober Pedy, Australia (Credit:JAXA)

Ryugu samples



Chamber C (TD2)

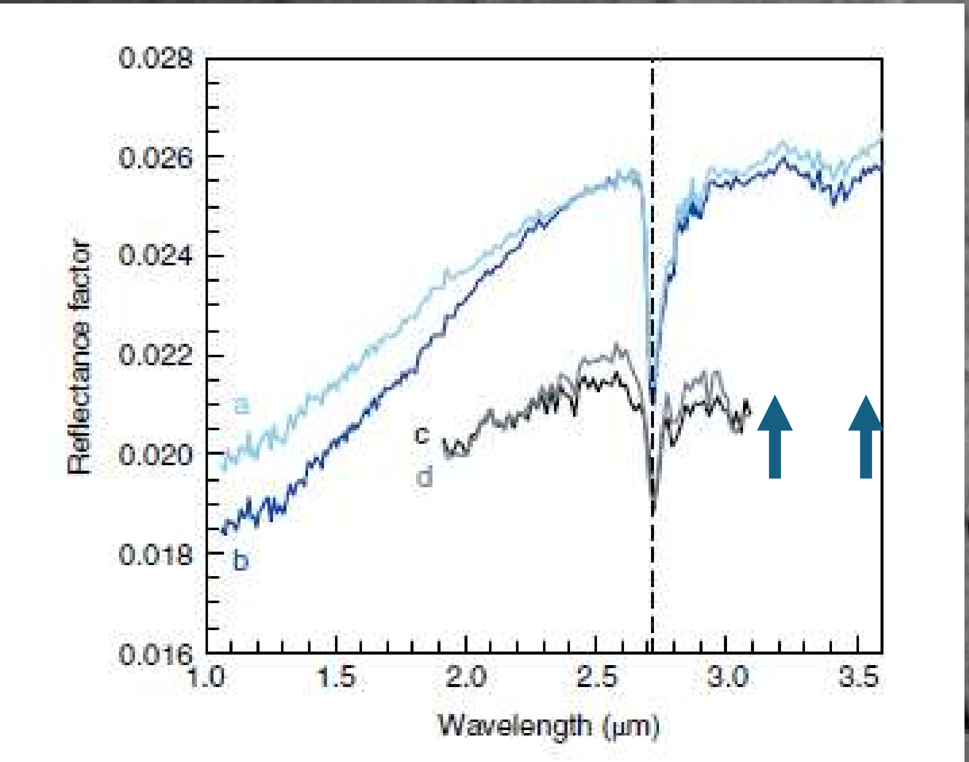


5.4 g of collected grains (2 grams from TD2)
(Goal: 100 mg- Watanabe+,2017)

Spectral investigation by MicrOmega

MicrOmega: Hyperspectral microscope operating in the NIR range (0.99-3.65 µm)

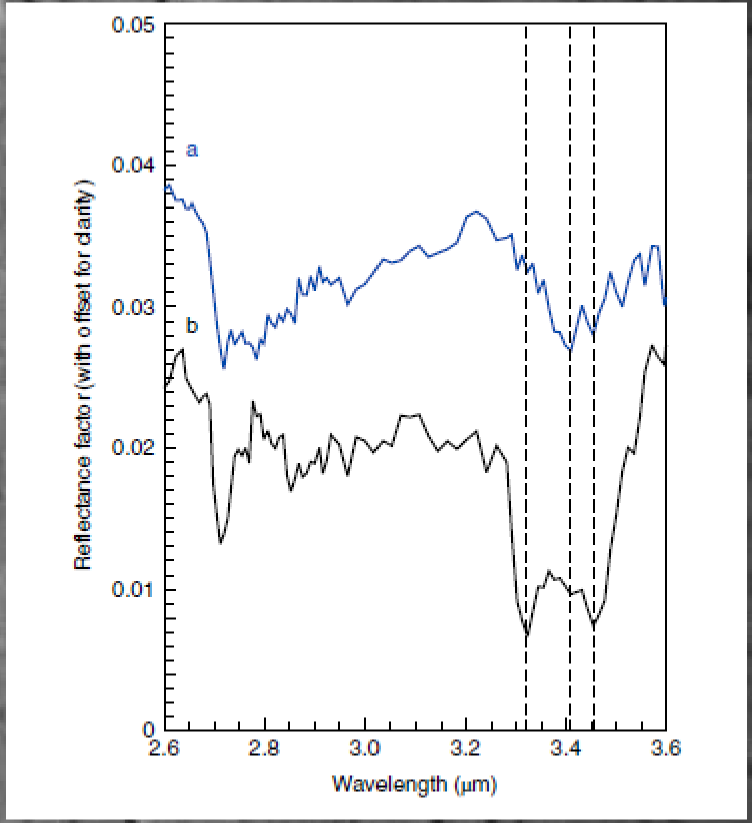
Average spectra of «bulk A» and «bulk C» on millimeter scale



- Spectral similarity with NIRS3 spectra, OH band at 2.72 µm (Mg-rich minerals)
- No significant differences between «bulk A» and «bulk C»
- Broad feature in the 3.3-3.5 µm range (CH-rich compounds)
- Faint absorption at 3.06 µm

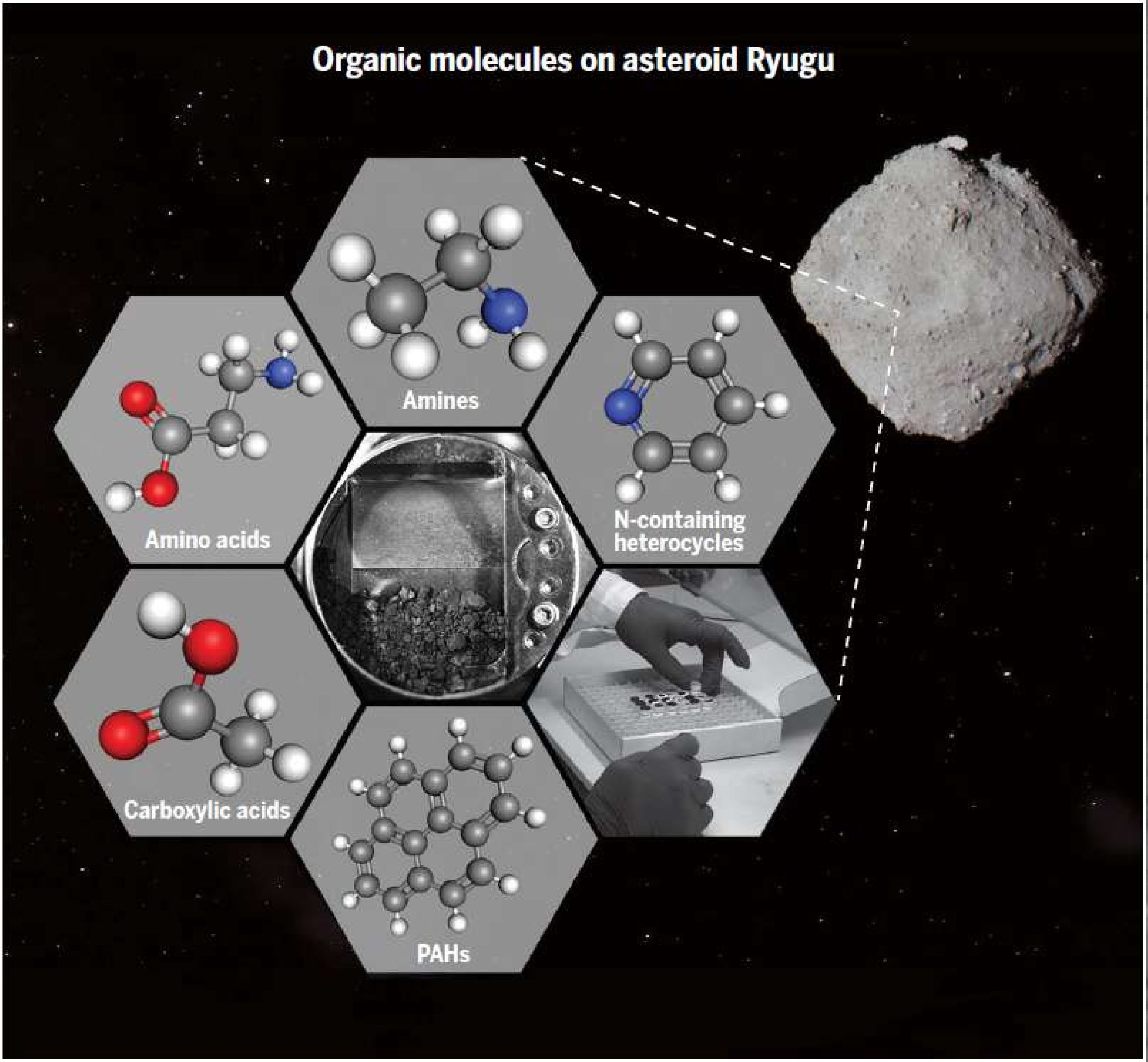
From millimeter to micron scale

Spectrum of a spot in bulk A (a) compared with a typical carbonate spectrum (b)



- Prominent 3.41 µm feature (CH_2 stretching)
- Weaker 3.38 µm feature (CH_3 stretching)

Soluble Organic Molecules (SOMs) in Ryugu's samples



Mass spectroscopy on Ryugu aggregate sample A0106 (<1mm diameter, 38.4 mg weight) collected on TD1 :

- organic molecules containing carbon, hydrogen, nitrogen, oxygen and/or sulfur
- Aliphatic amines (such as methylamine) and carboxilic acids (such as acetic acid) were detected likely retained as organic salts.

The presence of aromatic hydrocarbons implies hydrothermal processing on Ryugu's parent body and/or presolar synthesis in the interstellar medium (the protosolar nebula).

SOMs (including prebiotic molecules such as amino acids) were also found in carbonaceous chondrites meteorites (CI and CM), which might have delivered amino acids and other prebiotic organic molecules to the early Earth and other rocky planets.

The Ryugu's samples were exposed to SpWe, but the SOM is still preserved, likely by being associated with minerals. **These molecules can be transported throughout the Solar System**


Honor Award
「はやぶさ2」
HAYABUSA2
~小惑星リュウグウの往復探査の完璧な成功を記念して~
To commemorate the amazing success of the round-trip exploration to asteroid Ryugu
Galiano 殿
はやぶさ2探査機は、2195日の宇宙の旅を無事に終えて、
小惑星リュウグウの探査とそのサンプルの取得に成功しました。
この成功に導いた、あなたの熱意と献身的な御尽力に、
心より感謝いたします。
The Hayabusa2 spacecraft completed a 2195 day round-trip through space,
explored the asteroid Ryugu, and successfully collected samples.
We would like to express our heartfelt gratitude for
your dedication and enthusiasm that made this venture possible.
HAYABUSA2
2020
COME BACK TO EARTH
2021年12月
はやぶさ2プロジェクト
December 2021, Hayabusa2 Project

Thanks for your attention