



Press conference at LPSC  
19 March, 2019

# Hayabusa2 arrives at the carbonaceous asteroid 162173 Ryugu — a spinning-top-shaped rubble pile

Published online by the journal *Science* on 19 March, 2019

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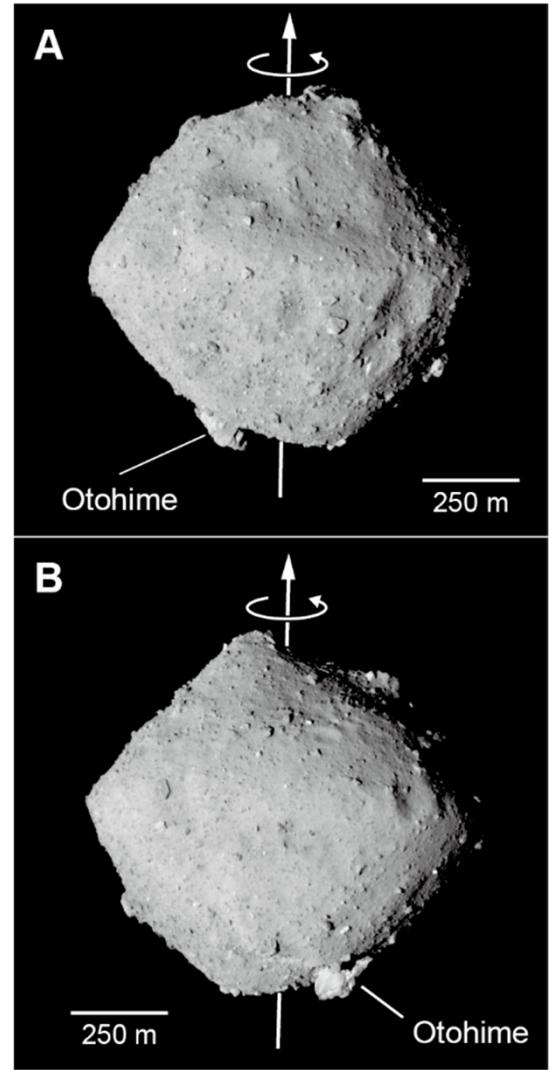
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# Background and summary

- *Hayabusa2* spacecraft arrived at carbonaceous asteroid Ryugu in June 2018, conducting remote-sensing observations & gravity measurement.
- Three papers based on the *Hayabusa2*'s observations of Ryugu are published online by *Science* today.
- This is one of the papers. We discuss the shape and structure of Ryugu based on shape models reconstructed from observations and other physical data.
- Main results are:
  1. Ryugu is a rubble-pile asteroid with a large internal porosity.
  2. The spinning-top shape with a prominent equatorial ridge (ER) of Ryugu was probably formed by a past rapid rotation.
  3. We identify a suitable sample collection site on the ER.

Fig. 1: Optical Navigation Camera – Telescope (ONC-T) images of Ryugu. [Watanabe+ 2019 *Science*]





# Method: Shape models of Ryugu

SfM: Structure from Motion  
SPC: Stereophotoclinometry

- Optical camera (ONC-T) images, LIDAR ranging data → Shape models of Ryugu
- Two types of shape models: SfM (Aizu University), SPC (Kobe University).

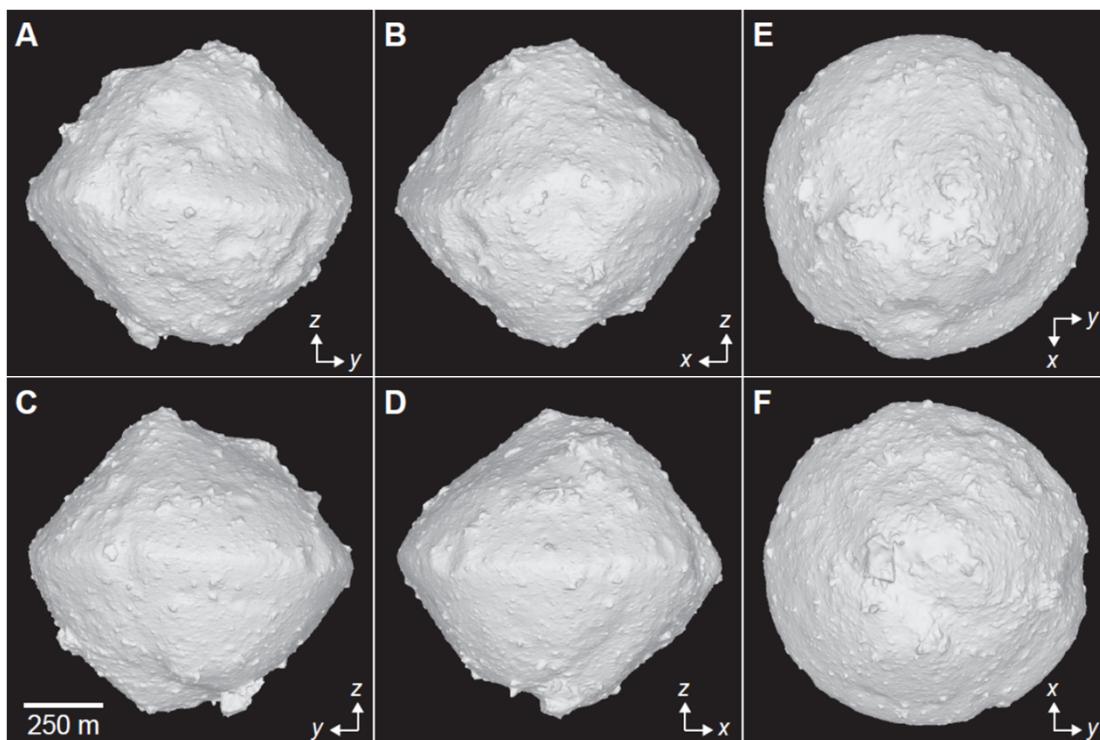


Fig. 2: SfM-based model (z to the north pole). [Watanabe+ 2019 *Science*]

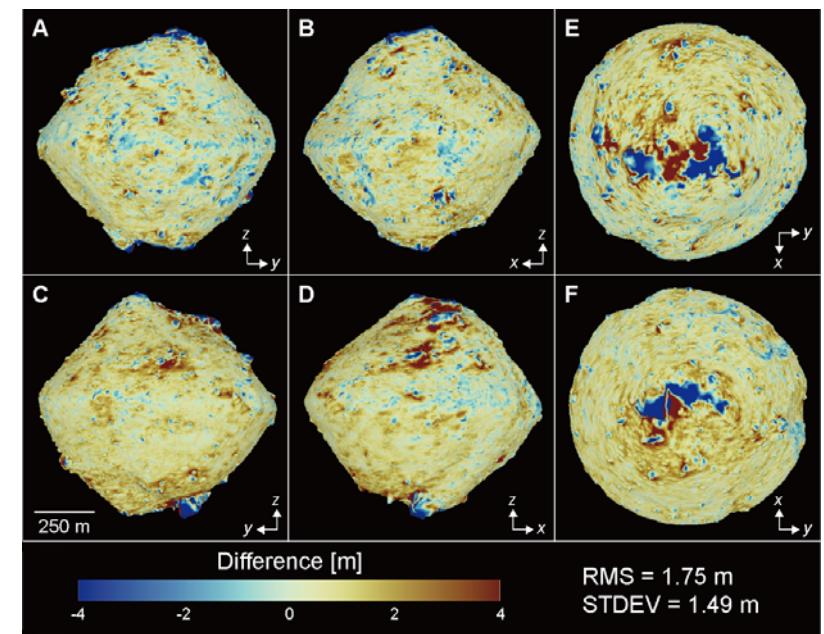


Fig. S2: difference map between SPC & SfM based models. [Watanabe+ 2019 *Science* (Supplementary Materials)]



# Result 1: Ryugu is a rubble-pile<sup>†</sup> asteroid

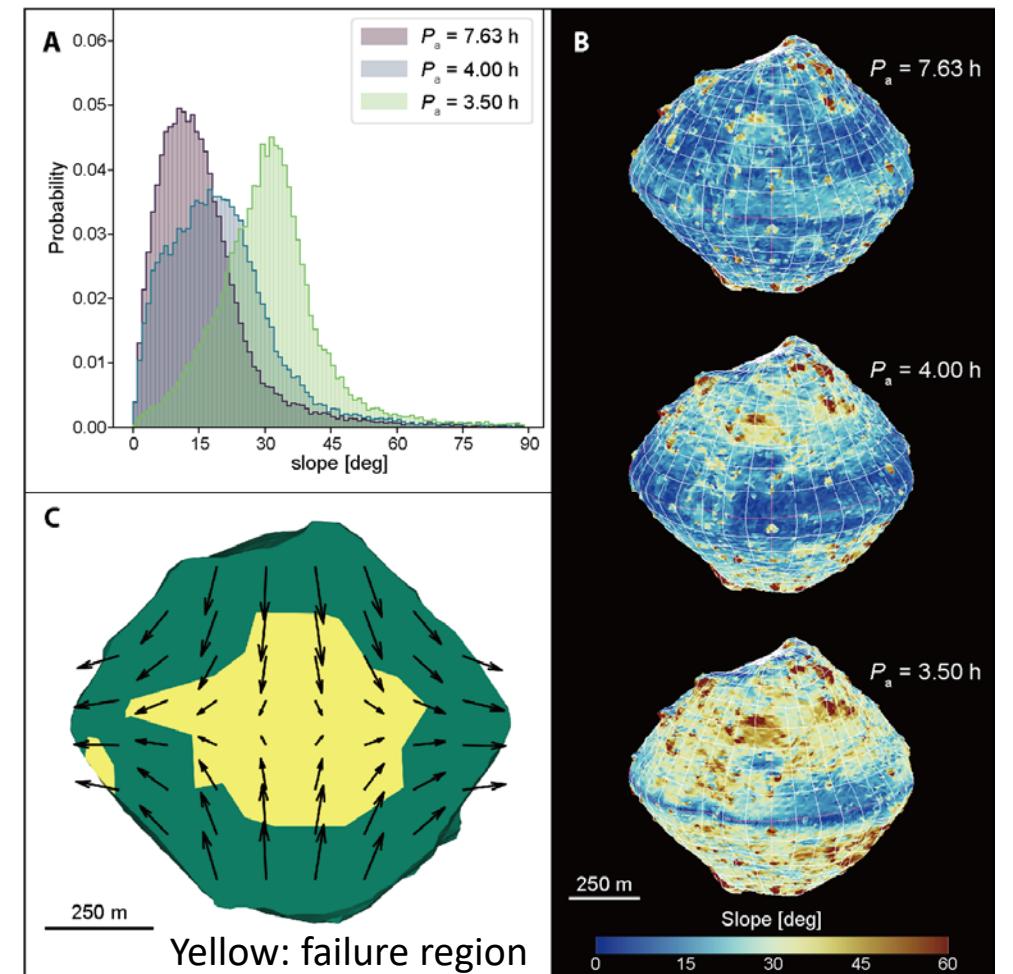
<sup>†</sup>formed from re-accumulation of fragments generated by catastrophic disruption events of parent bodies

- Bulk density of Ryugu:  $1.19 \pm 0.02 \text{ g cm}^{-3}$ 
  - Ice? No, because equilibrium temperatures are higher than the sublimation temperature of water ice.
  - If the constituent grain density is similar to those of carbonaceous chondrites, **Ryugu's porosity is more than 50%**. (Porosity of rubble-pile Itokawa\*  $\sim 44 \pm 4\%$ )
- Abundant large boulders on its surface
  - Gravitational capture of ejecta after impact cratering on this body cannot be responsible for these large boulders.
  - These boulders are most likely **fragments that accreted during the formation of Ryugu**, after disruption of its parent body.
- These strongly support that Ryugu is a rubble-pile asteroid.



## Result 2: Spinning-top shape of Ryugu was formed by a past rapid rotation

- Ryugu's shape may have been produced by rotationally induced deformation.
  - Most of the known top shapes are rapid rotators but Ryugu is rather slow (7.63 h).
  - **Surface slope analysis\***: the variation in surface slopes becomes minimum at a spin period of 3.5 hours [Fig. 3A, B].
- A possible scenario may result from a late-stage rotational acceleration.
  - Deformation will occur either in the interior or on the surface, depending on the internal structure.
  - Numerical simulations show that **the interior failure occurs if Ryugu has a uniform, weak interior** [Fig. 3C].
  - Surface landslides from mid-latitudes to the equator may be driven by an increase in strength of the asteroid with depth.



\* See Appendix

Fig. 3: Surface slope distribution and failure mode analysis\*. [Watanabe+ 2019, *Science*] 5/8

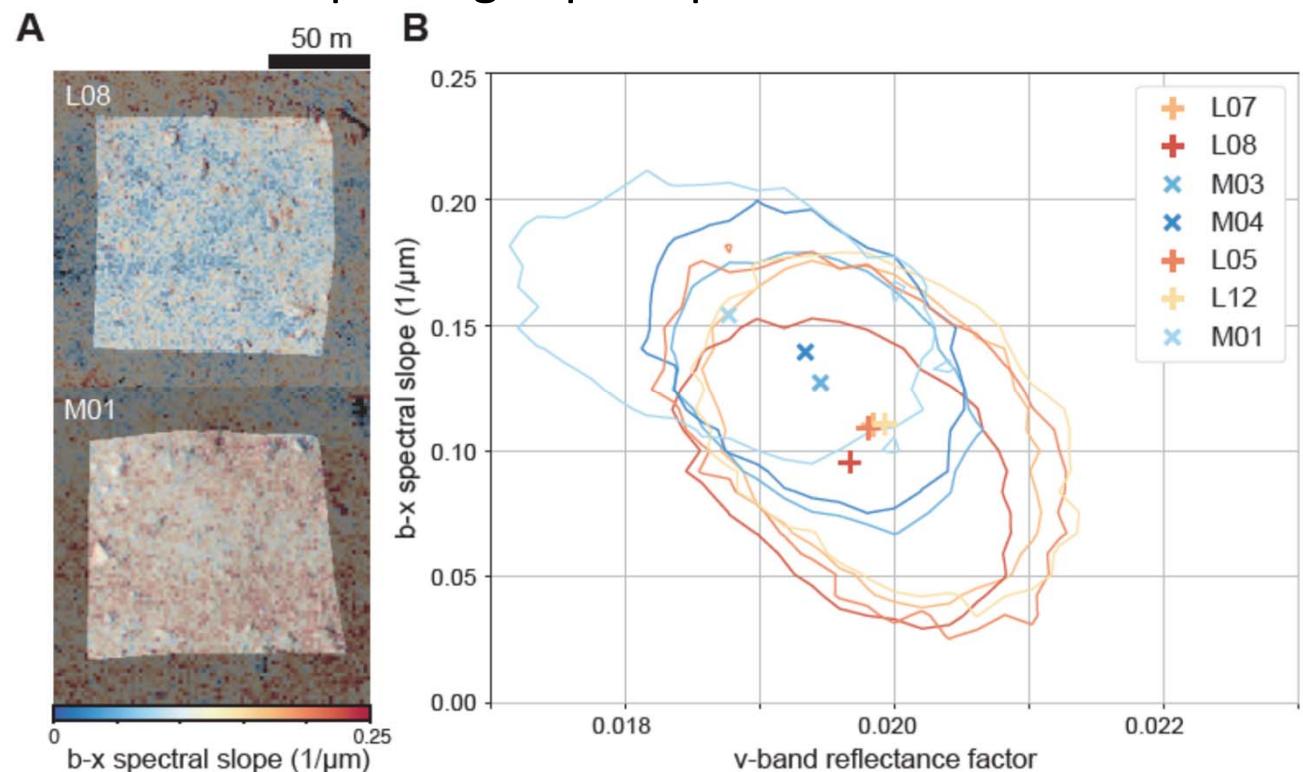


## Result 3: Identification of a sampling site

Based on comprehensive assessments\*, we identified a potential landing site (L08) on the equatorial ridge (ER) to perform material sampling with the prospect of giving further constraints on the evolution of this spinning-top-shaped asteroid.

\*For example, color analysis [Fig. 4] shows brighter, bluish materials are on the ER [see also Sugita+ 2019 *Science*], indicating their freshness if the effect of space exposure leads to reddening and darkening.

Fig.4: (A) “Color” (spectral slope) images of two representative candidate sites: L08 on the ER and M01 in mid-latitudes.  
(B) Brightness vs “color” diagram of each candidate site.  
[Watanabe+ 2019, *Science*]





# Perspectives

- This study shows that the formation process of asteroid shapes is closely related to the material strength.
- SCI impact experiment planned in April will provide us further information of strength of the surface layer of Ryugu.
- Return sample will reveal the chronology of materials on the equatorial ridge. Then we can distinguish the formation scenario of the spinning-top shape.
- Comparative study of Ryugu & Bennu will tell us their commonalities and individualities.
- **Strength of carbonaceous asteroids is key to clarify the delivery processes of water and organics to the early Earth.**

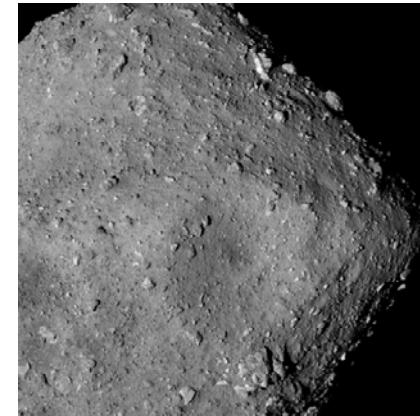


Fig. A1: Urashima Crater on Ryugu.  
Credit: JAXA/  
U Tokyo/Kochi U/  
Rikkyo U/Nagoya U/  
Chiba Inst of Tech/  
Meiji U/U Aizu/AIST

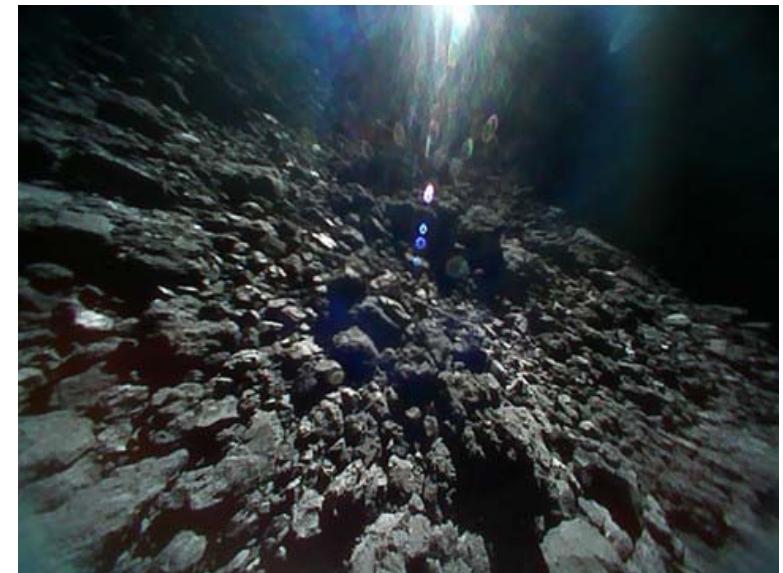


Fig. A2: Surface of Ryugu taken by rover MINERVA-II1B. Credit: JAXA



## Appendix: Surface slope\* & failure mode analyses

- Fig. 3: Using the derived bulk density and shape model, we analyzed the surface slope distributions and failure mode at different rotation periods (current rotation period: 7.63 hours; 4.0 hours; and 3.5 hours) assuming a uniform density distribution.
- (A) Surface slope distributions.
- (B) Surface slope maps.
- (C) Failed region (yellow) and deformation vectors on the meridional cross-section at a spin period of 3.5 hours.
- At the current rotation period, the mean surface slopes is  $11.8^\circ$ , but Ryugu exhibits latitudinal variation; the mid-latitudes have lower slopes while the equatorial ridge have higher slopes.
- At the rotation period of 3.5 h, which is almost equal to the critical spin limit that the centrifugal force exceeds gravity at the equator, the surface slope distribution is centered at  $31^\circ$ . The variation in surface slopes becomes minimum at this rotation period.

\*The angle between the normal to the surface and gravity (gravitation + centrifugal force)

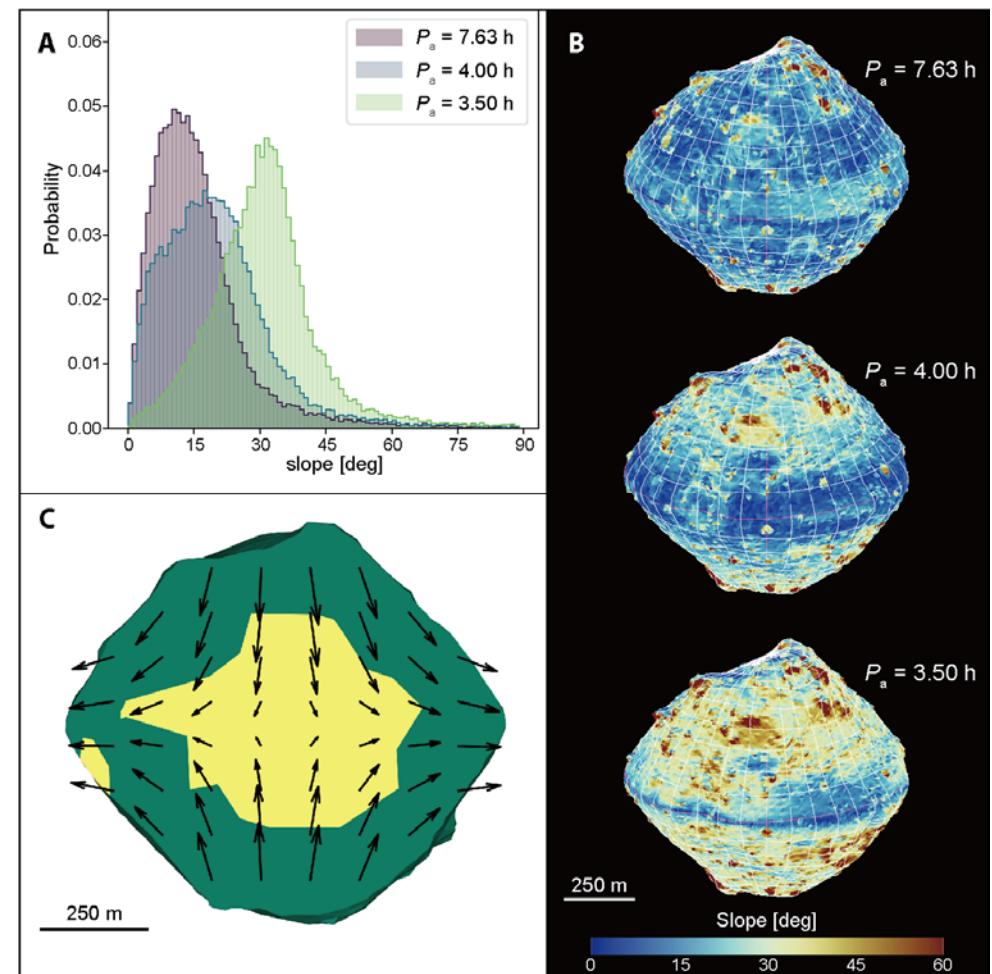
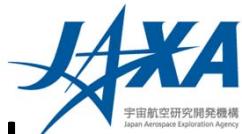
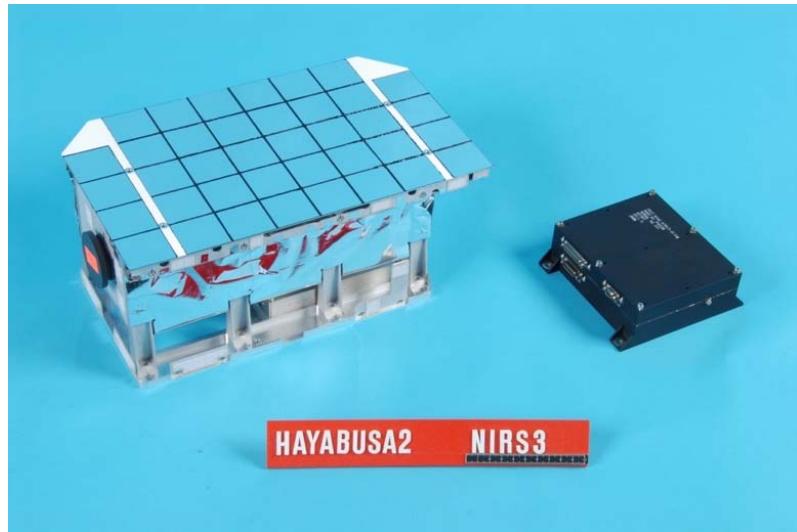


Fig. 3 of Watanabe+ 2019, *Science*

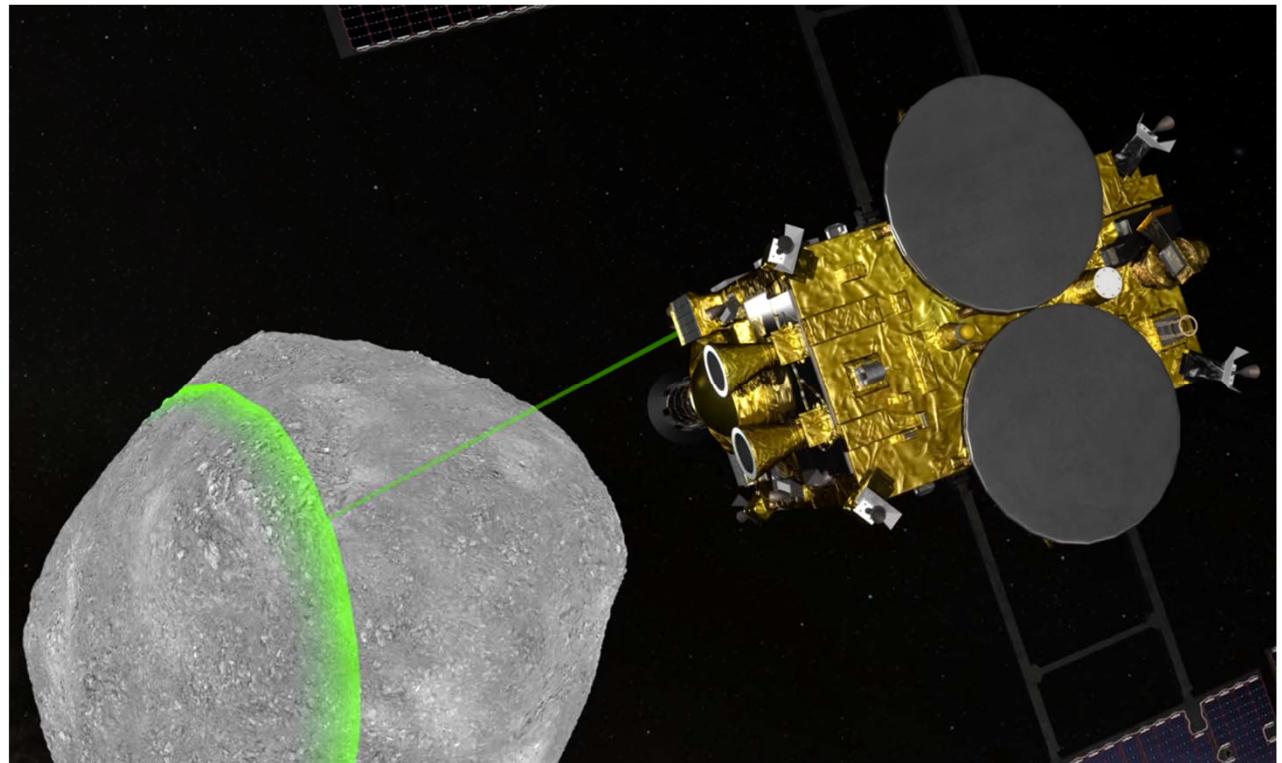


# The surface composition of asteroid 162173 Ryugu from Hayabusa2 near-infrared spectroscopy

*Kitazato et al., Science (2019)*



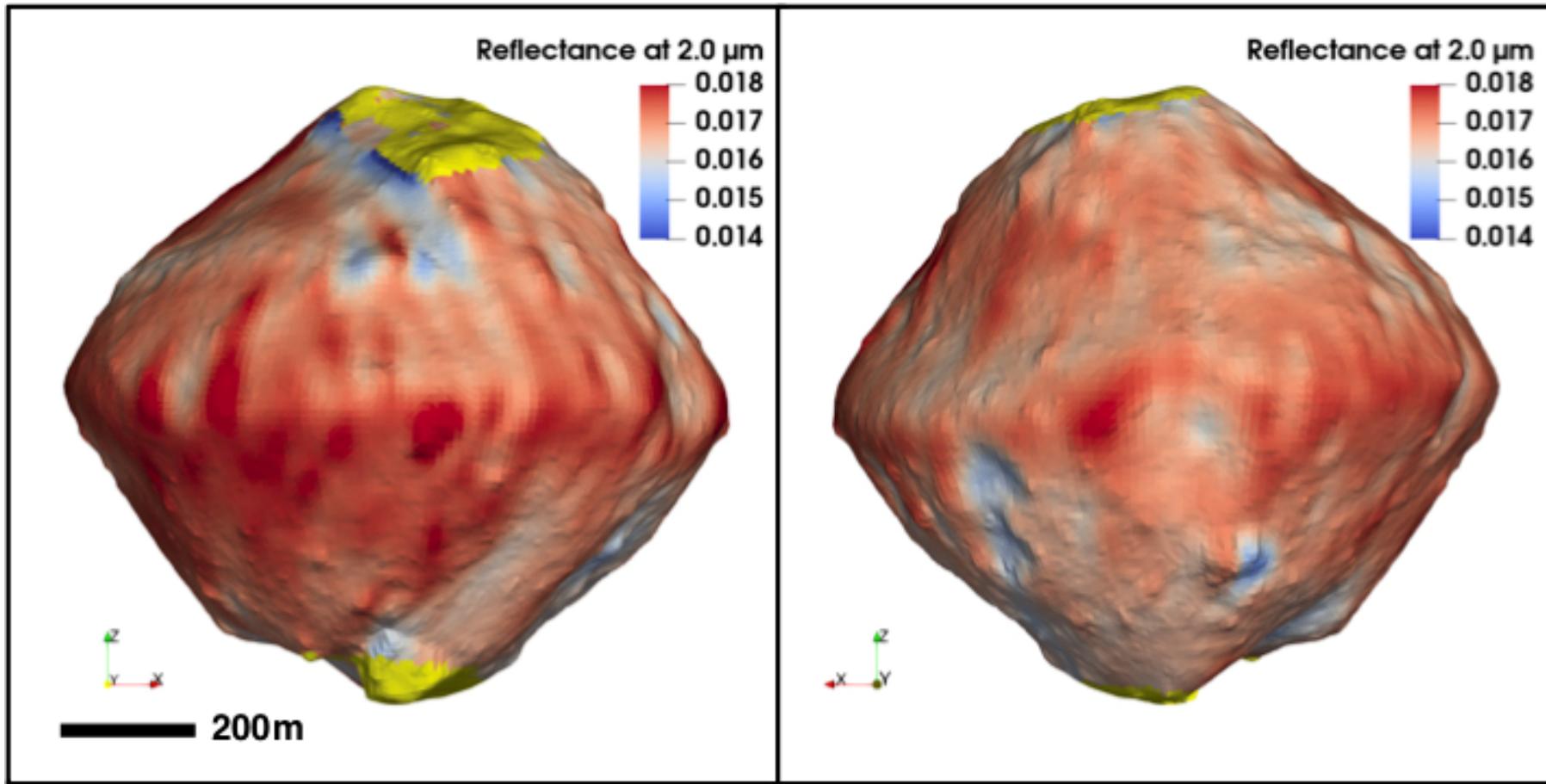
Near Infrared Spectrometer (NIRS3)  
Credit: JAXA





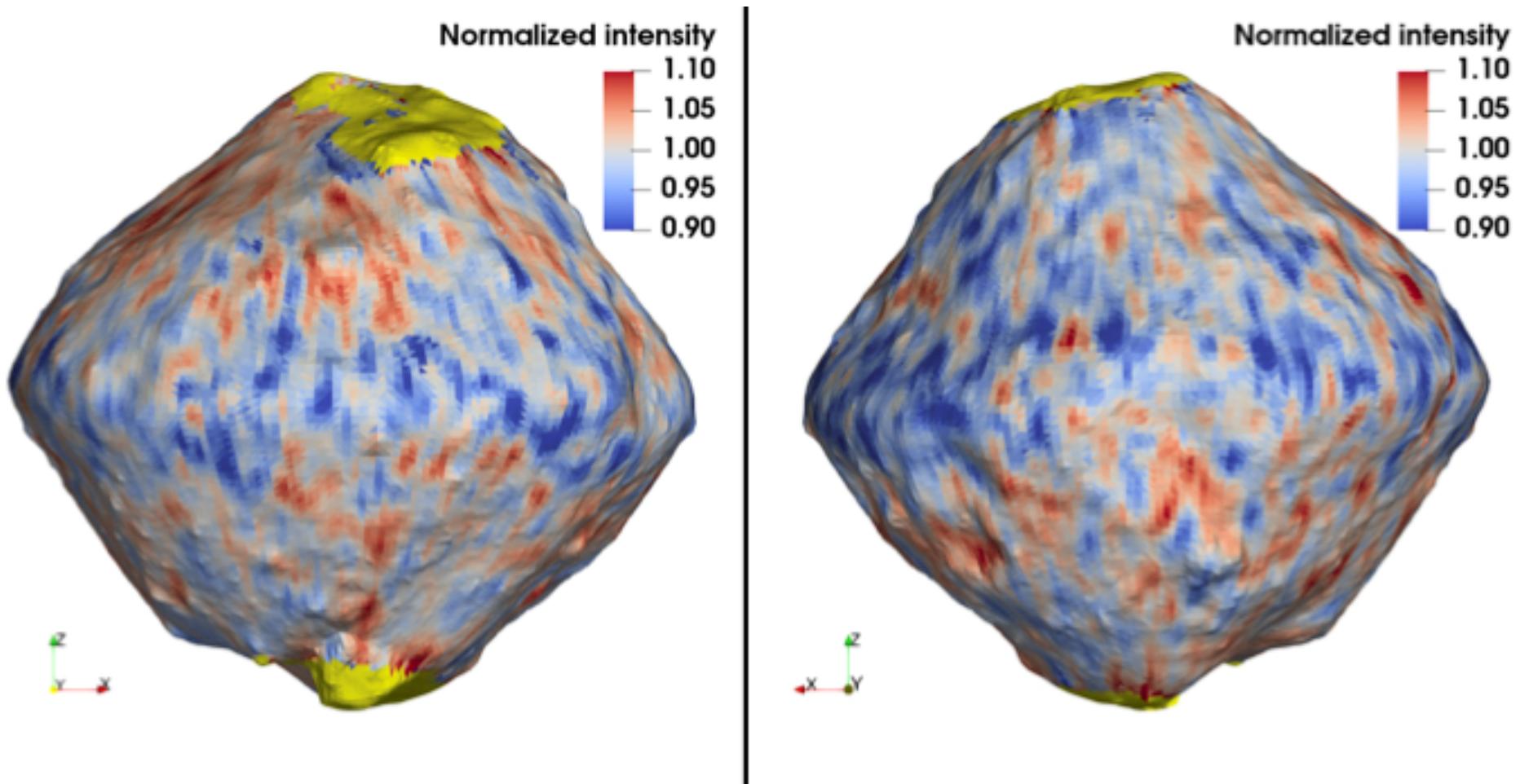
# Surface of Ryugu is Extremely Dark

JAXA  
宇宙航空研究開発機構  
Japan Aerospace Exploration Agency



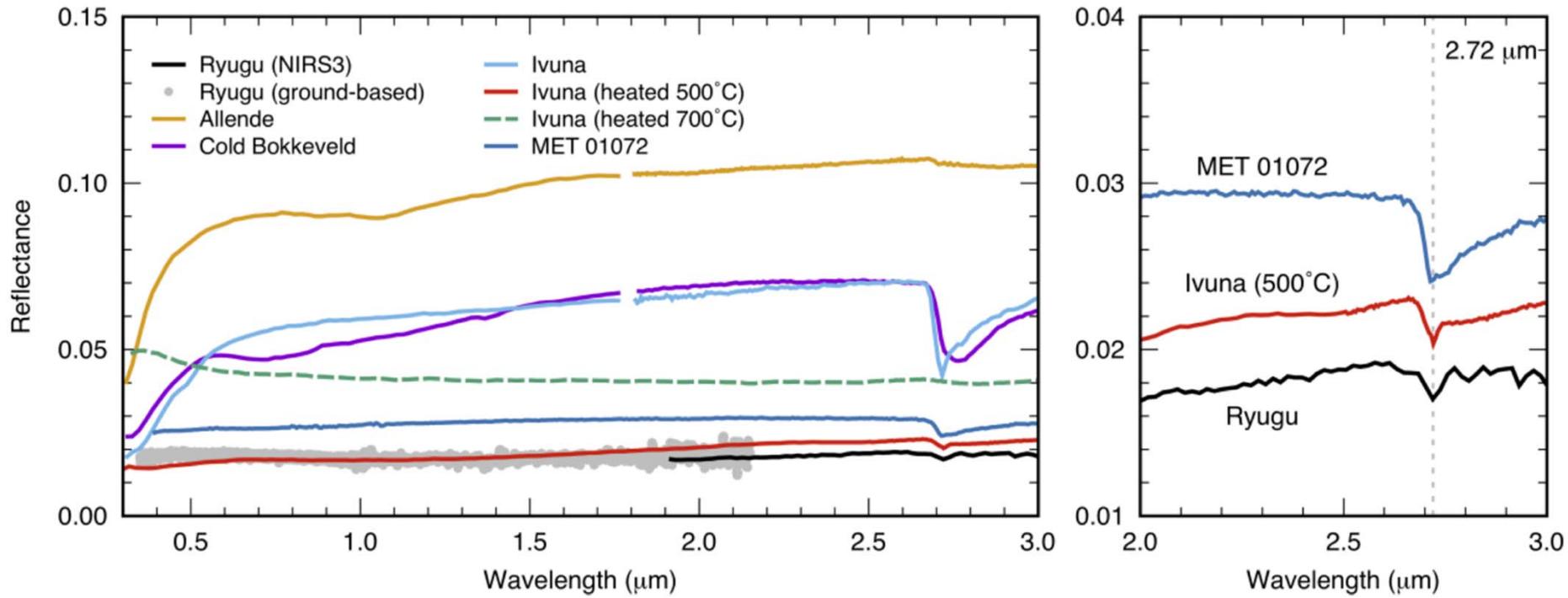


# A Feature Due to OH is Observed Everywhere





# Comparison of Ryugu with meteorite spectra



From Kitazato et al., Science (2019)

# The geomorphology, color, and thermal properties of Ryugu: Implications for parent-body processes

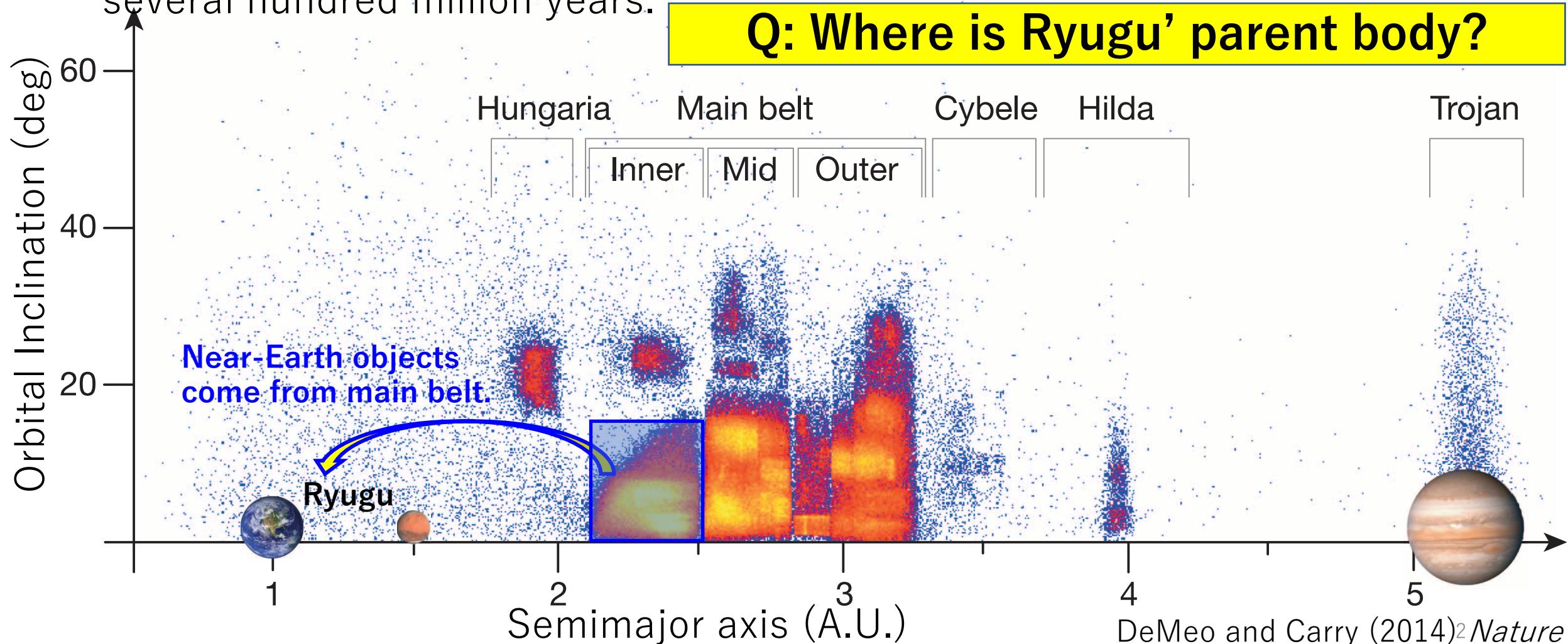
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DOI:10.1126/science.aaw0422

# The origin of Ryugu

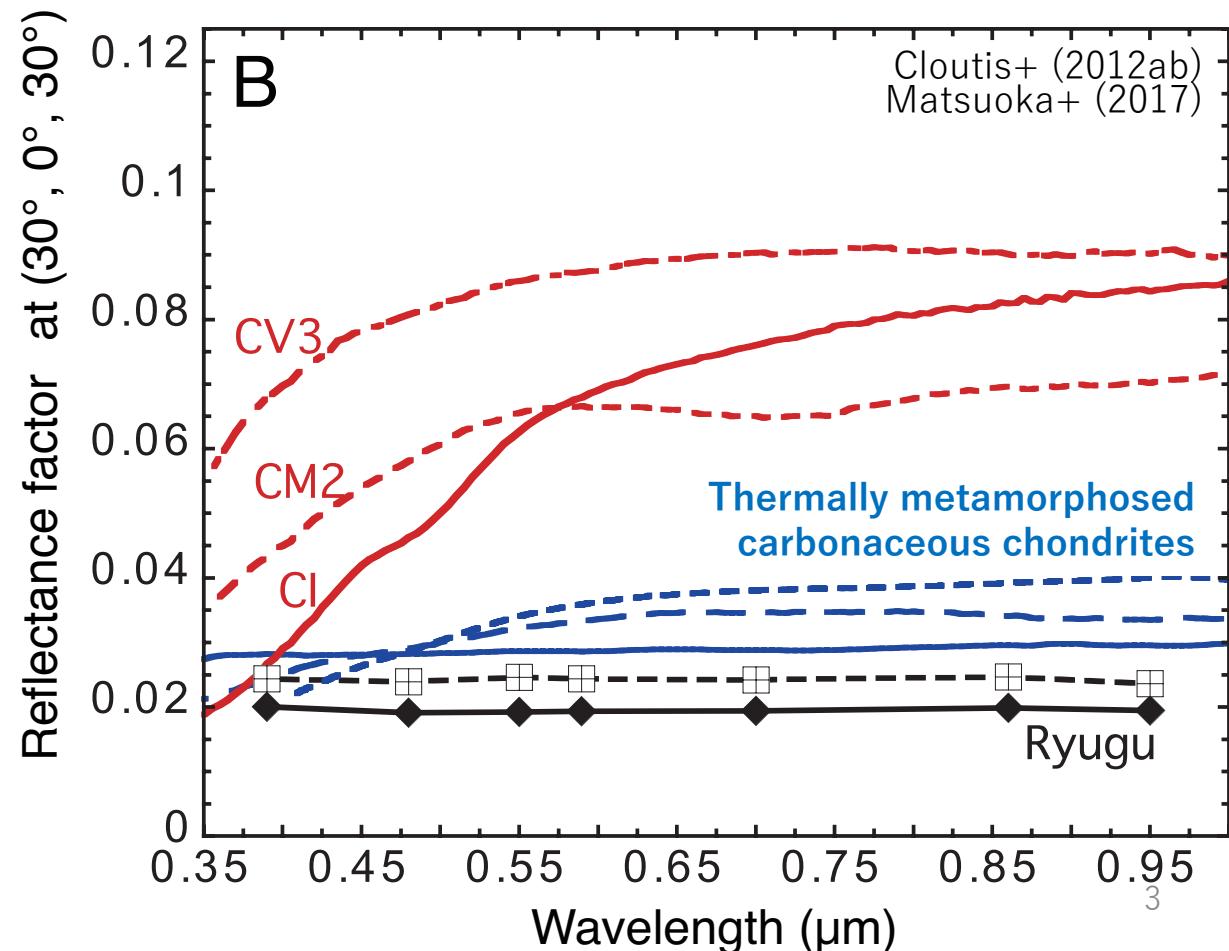
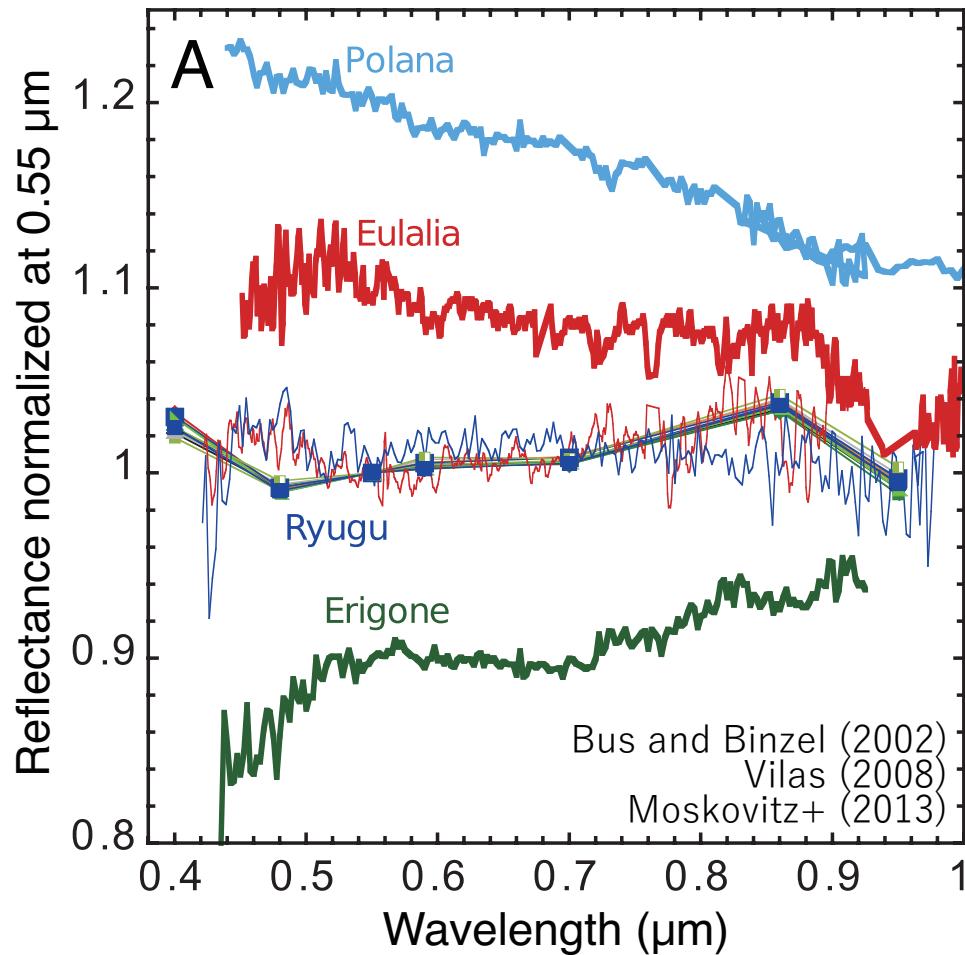
- Ryugu came from the inner main belt (~90% Michel&Delbo 2010, ~80% Bottke+2015).
- Ryugu is too small to survive 4.6 Byr of Solar System history (e.g., O'Brien+2005).  
→ It must have been produced from a larger and older parent body in the last several hundred million years.

**Q: Where is Ryugu' parent body?**

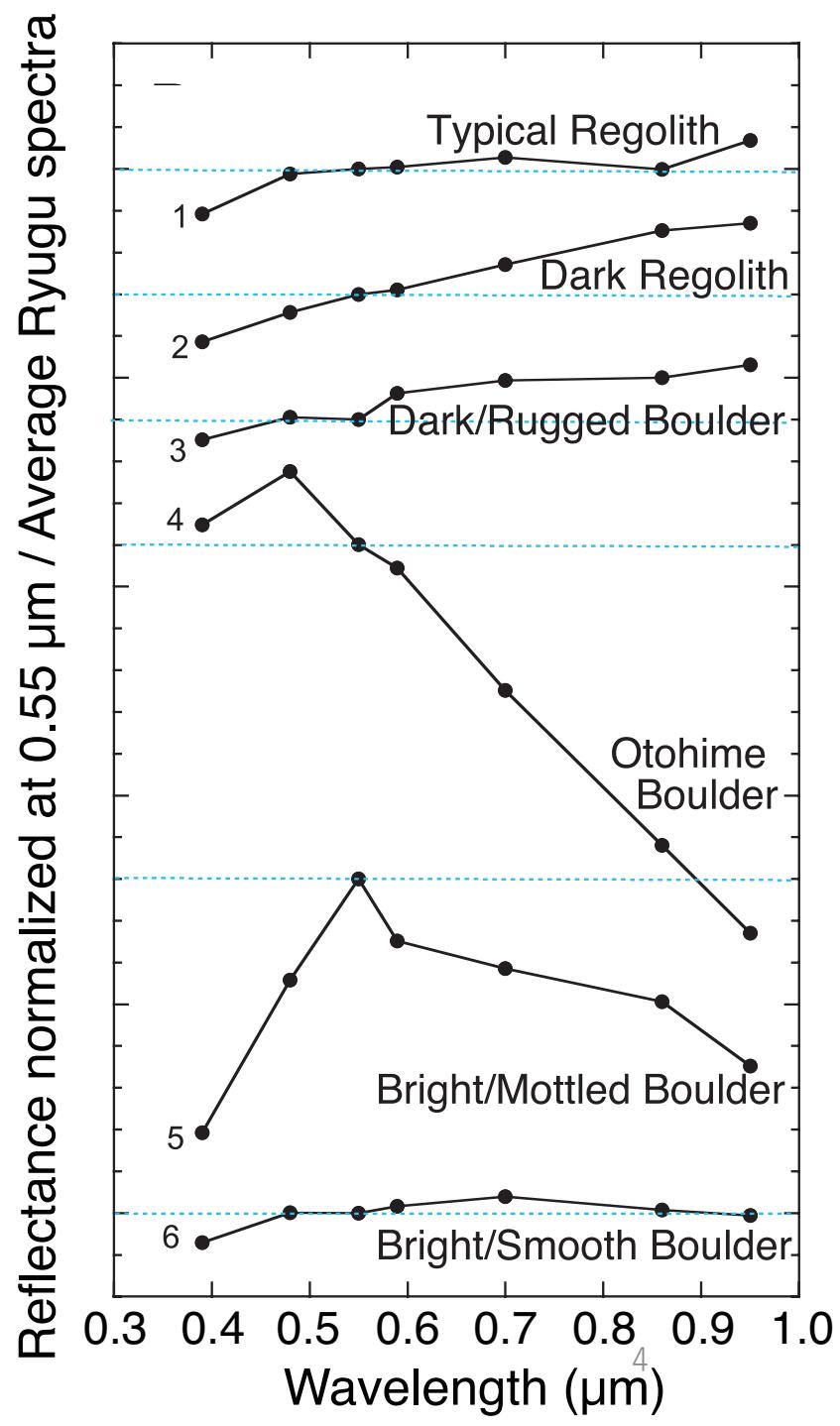
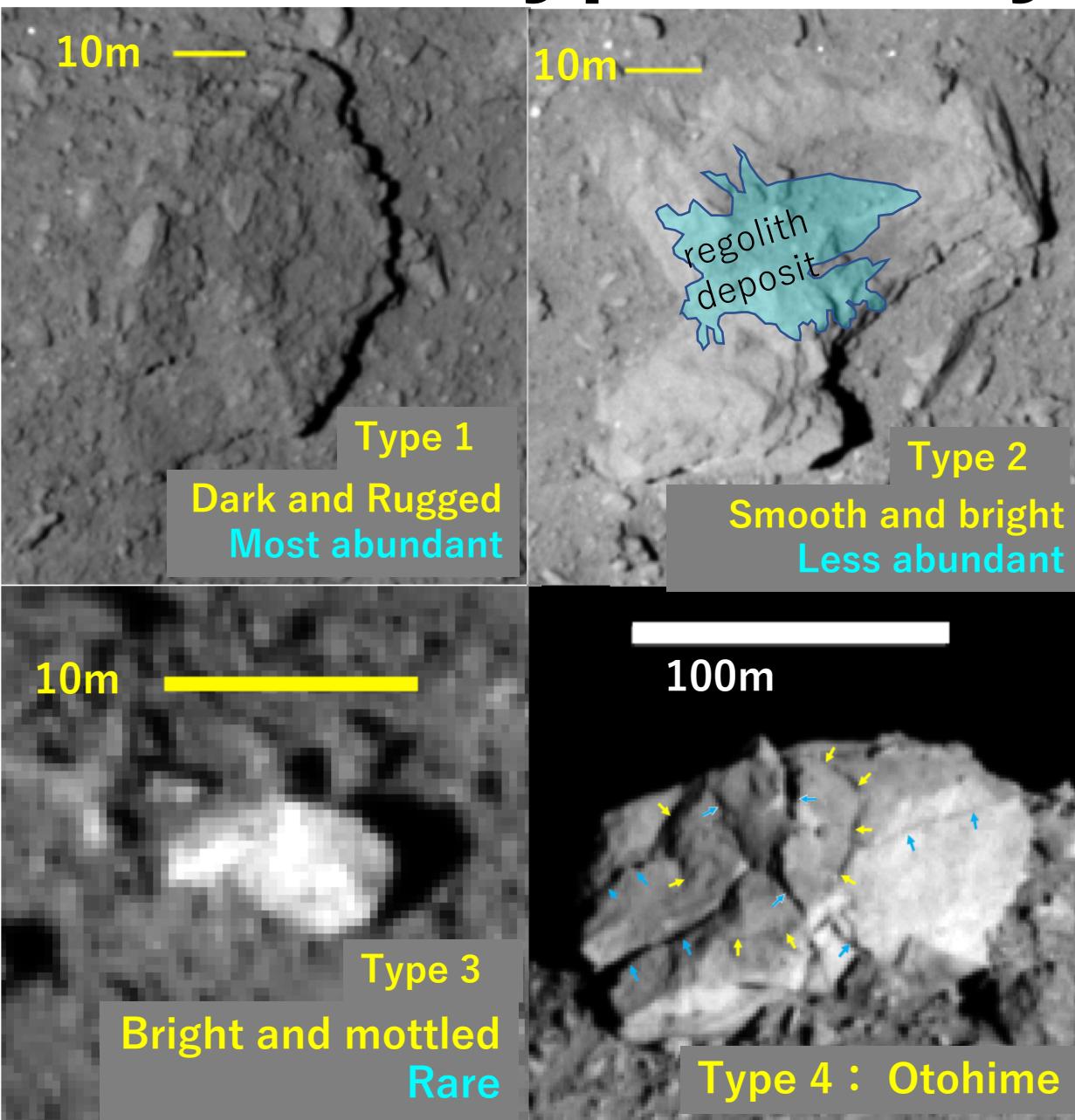


# Ryugu's average color

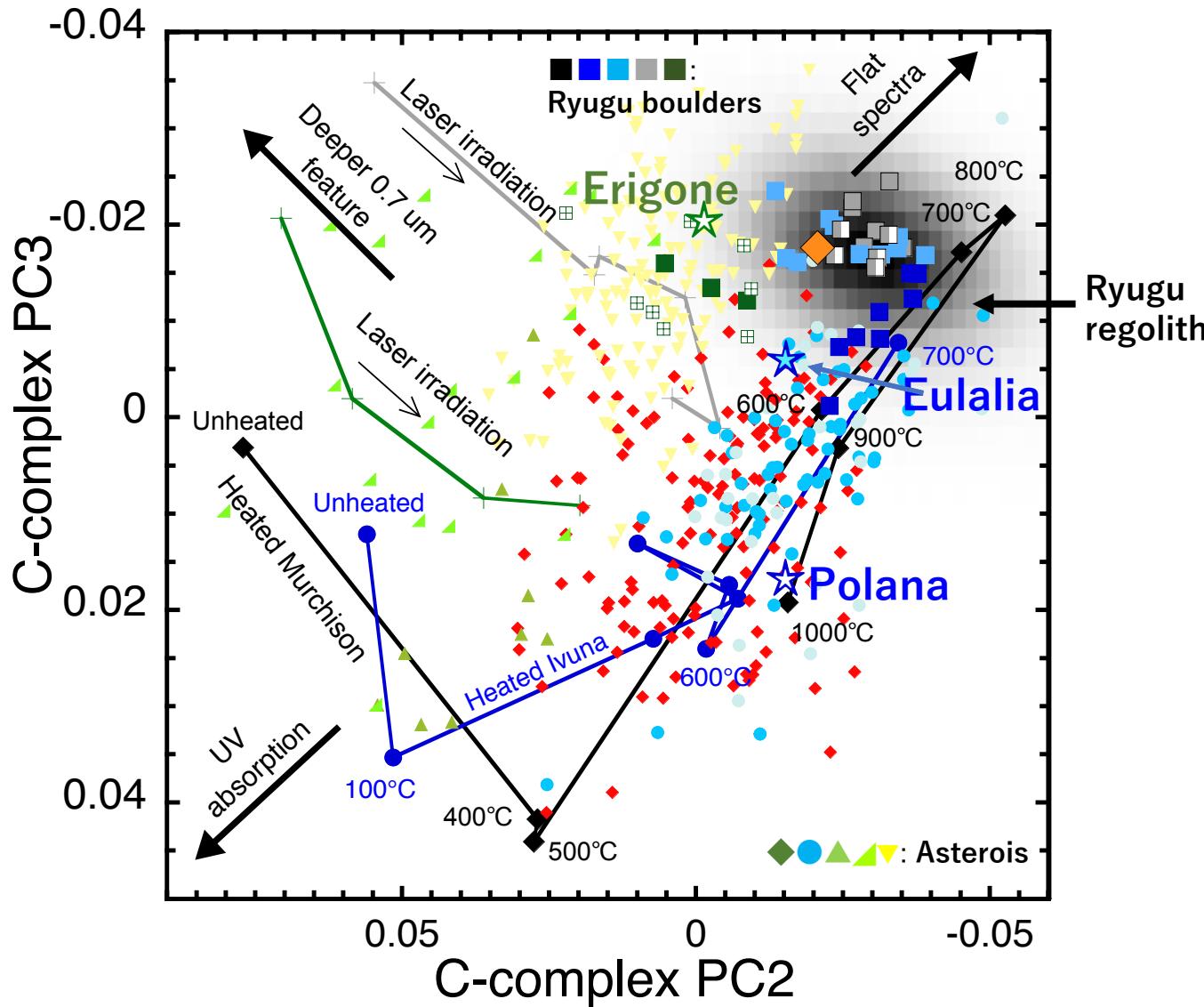
- Ryugu's color matches **Polana** and **Eulalia** families in the main asteroid belt.
  - No 0.7- $\mu\text{m}$  absorption or UV absorption.
- Ryugu's color matches best with thermally metamorphosed carbonaceous chondrites.
  - Most carbonaceous chondrites are much brighter than Ryugu.



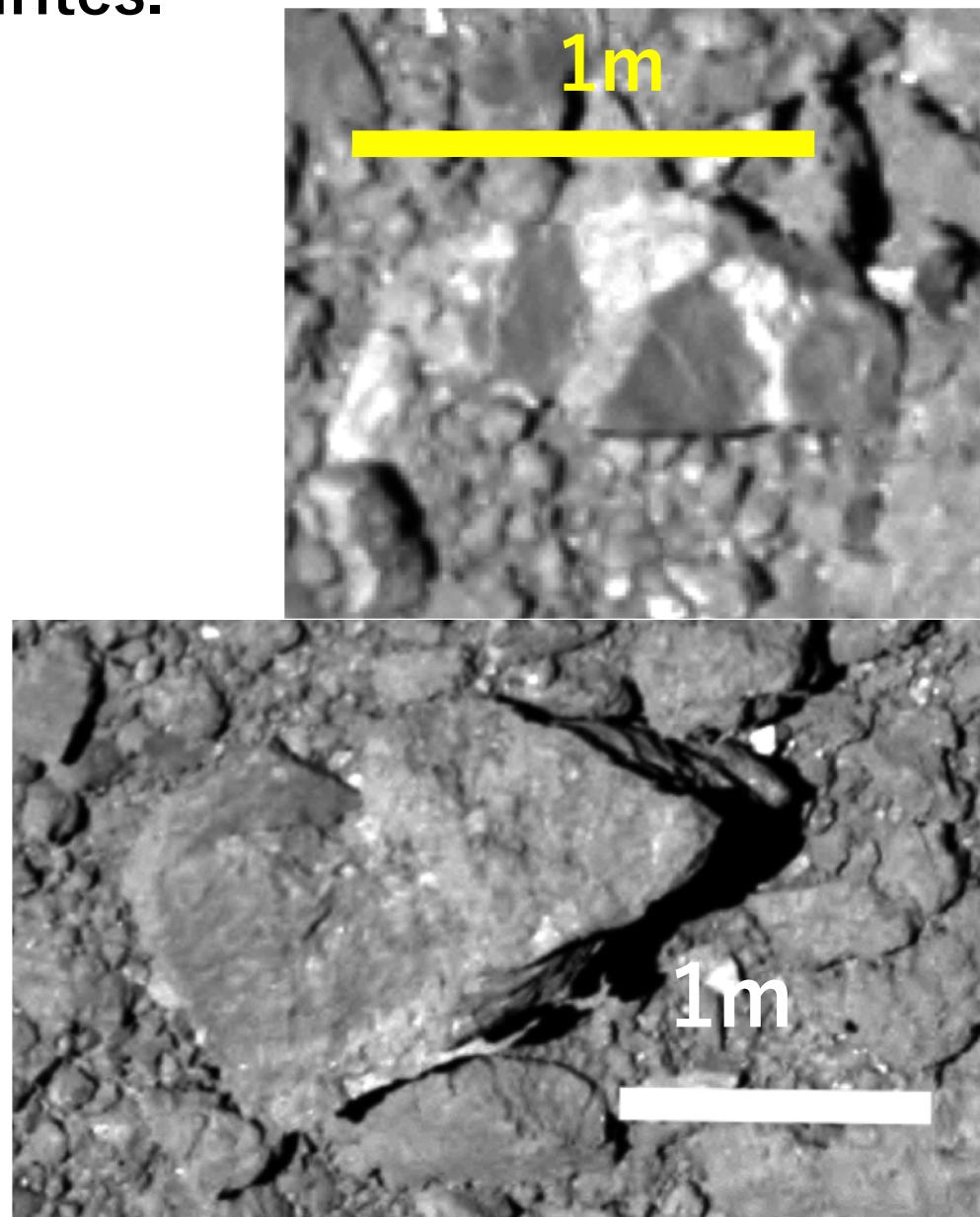
# Four boulder types on Ryugu



Color variation in boulders on Ryugu is consistent with dehydration trends of carbonaceous chondrites.



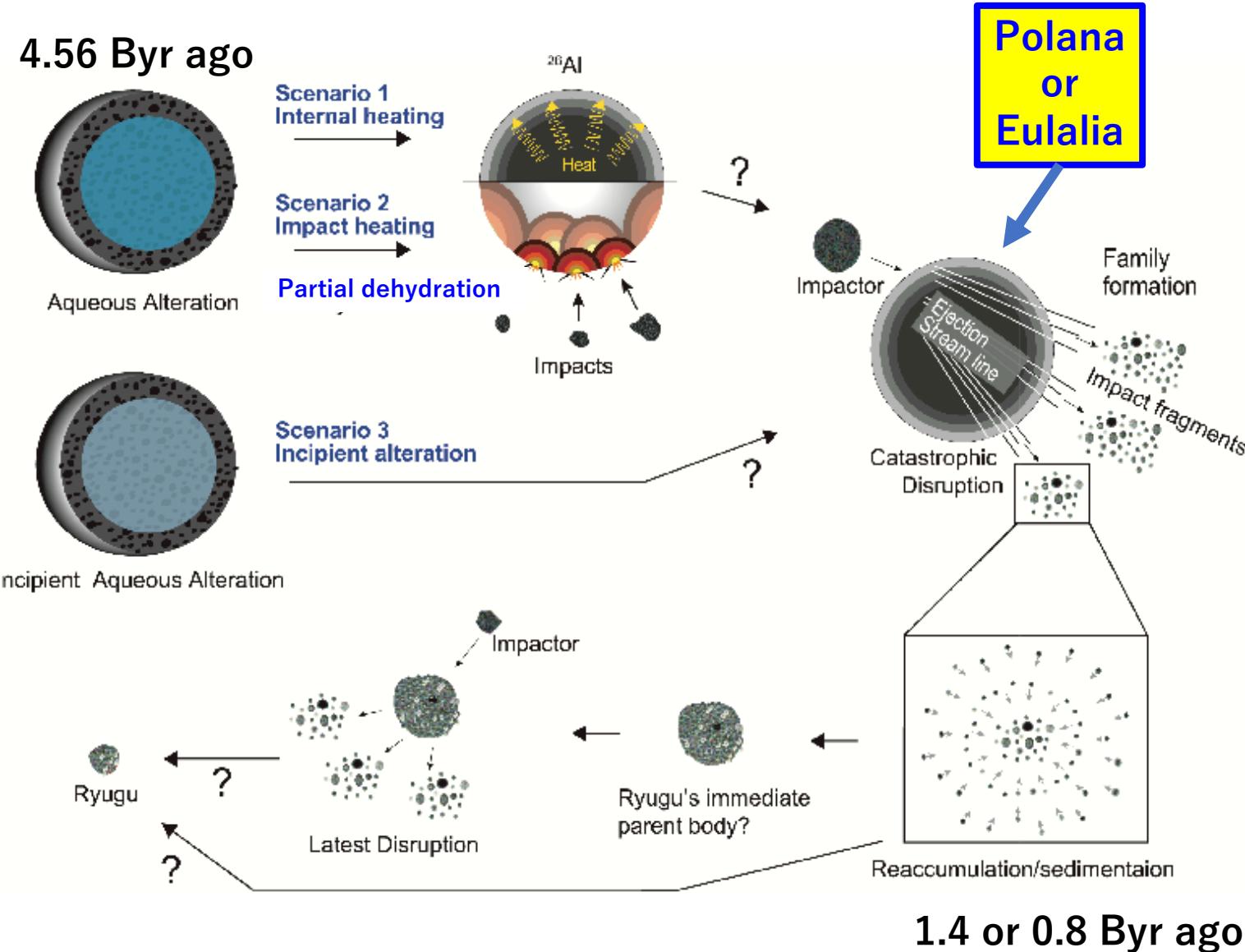
Impact Breccia!



# Conclusions

## The evolution of Ryugu and its parent body

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



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

# Future outlook and significance

- Analysis of returned samples may allow us to measure the collision age of Ryugu.
  - We can probably tell which is the parent body:  
Polana (~1.4 By) or Eulalia (~800 My)
- Polana and Eulalia families delivers the largest amount of C-type fragments to Earth.
  - The amount of water and organics delivered to Earth via asteroids may be controlled by such dehydration due to radiogenic heating in parent bodies.