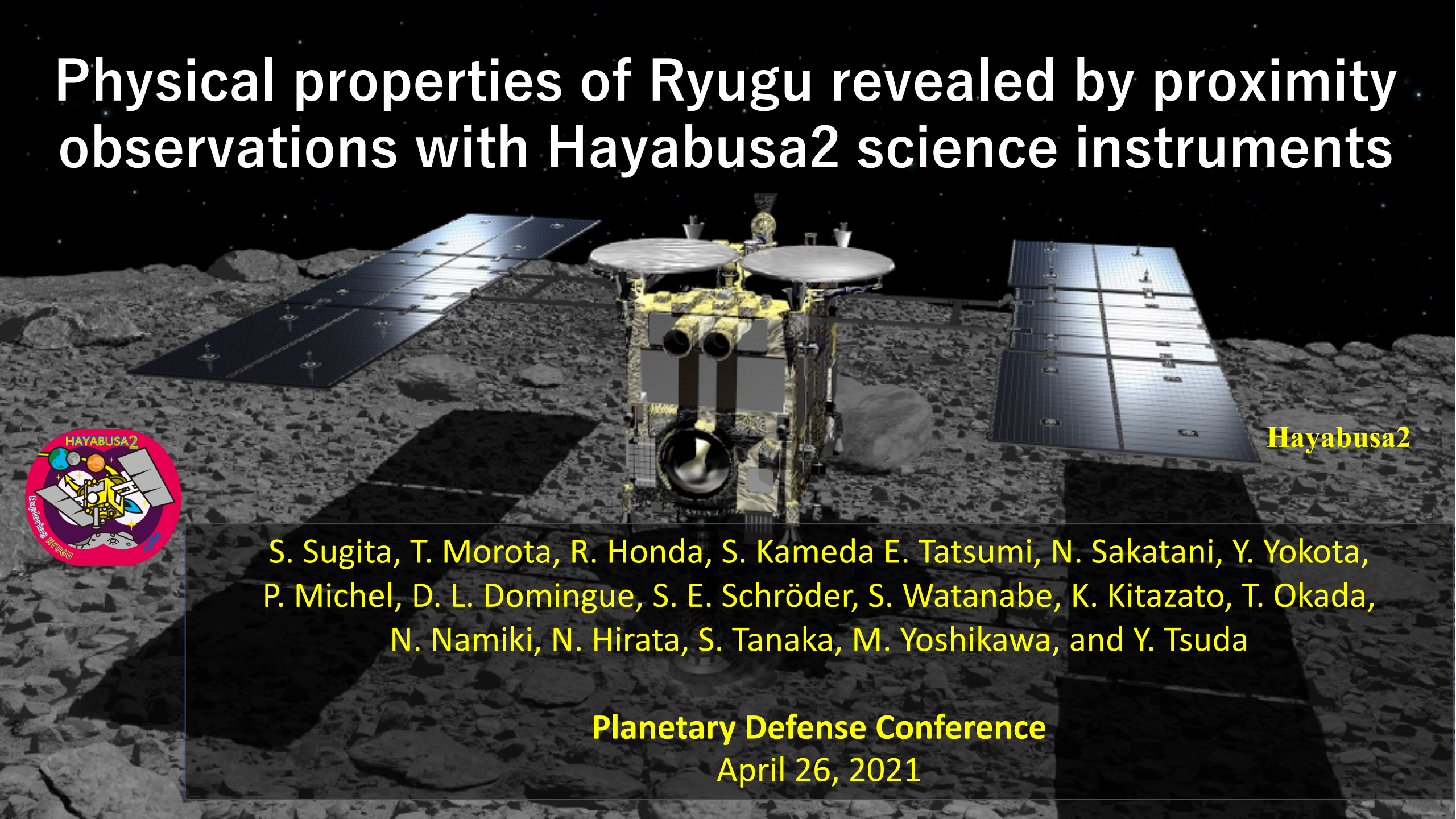
Physical properties of Ryugu revealed by proximity observations with Hayabusa2 science instruments



S. Sugita, T. Morota, R. Honda, S. Kameda E. Tatsumi, N. Sakatani, Y. Yokota,
P. Michel, D. L. Domingue, S. E. Schröder, S. Watanabe, K. Kitazato, T. Okada,
N. Namiki, N. Hirata, S. Tanaka, M. Yoshikawa, and Y. Tsuda

Planetary Defense Conference
April 26, 2021

Hayabusa2 Actual Observation Timeline

2018: Rapid resolution improvement 2019: Physical Contacts with Surface

Altitude

Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov

100s km

Approach

10s m/pix

Box A

Box B (S. pole)

20 km

Box C

Mid Alt

5 - 7 km

Box C

Gravity measurement

1 km

TD-RH1

MASCOT

2 m/pix

MINERVA

50-60 m

TD-R1A TD-R3

20 m

50 cm/pix

10 m

10 cm/pix

1 m

6 mm/pix

Solar Conjunction

Box A

Box B

Box C

SCI Crater

Pre-Impact Scan Obs.

Post-Impact Scan Obs.

SCI Impact

DO-S01

PPTD-TM1

1st TD

1mm/pix

PPTD-TM1A

PPTD-TM1B

2nd TD

Departure for Earth

Box B (N. pole)

Box A

Box B

Box C

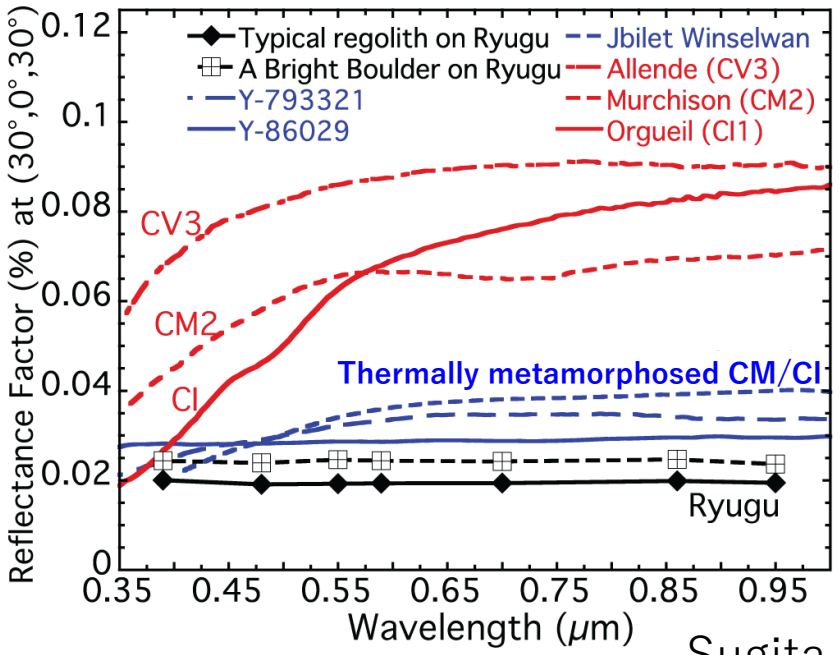
Box C

TM & MNRV-II-2 release for gravity measurement

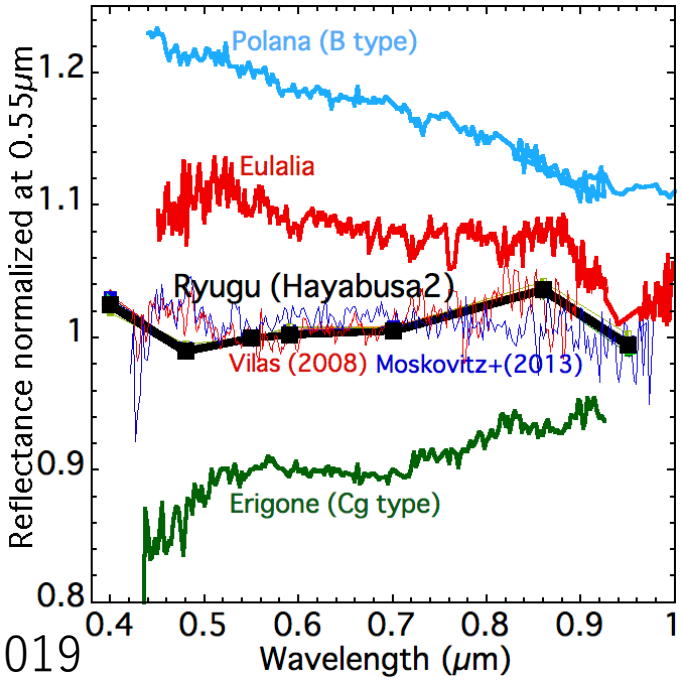
Sugita et al. (2019) Image credit : JAXA/UTokyo/Kochi U/Rikkyo U/Nagoya U/Chiba Inst Tech/Meiji U/U Aizu/AIST/IMU/

General Characteristics of Ryugu

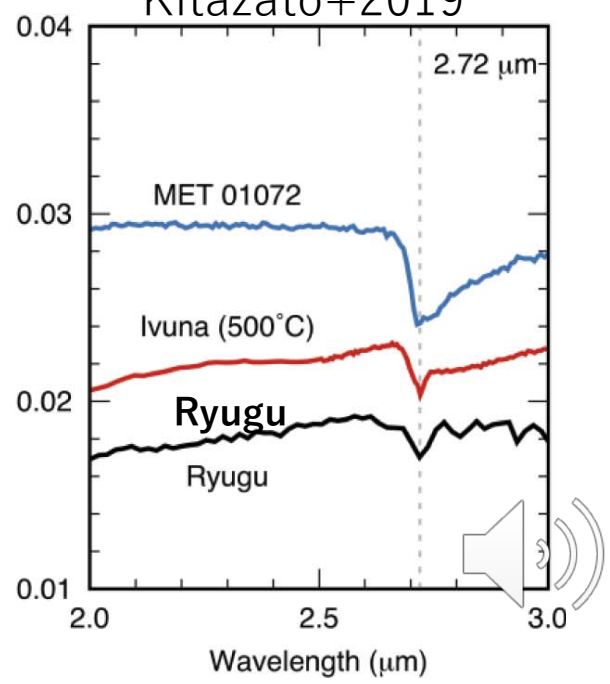
- **Top shape** (Watanabe+2019, Sugita+2019)
- **Rubble pile**
  - High abundance of large boulders (Sugita+2019)
  - Low ρ (1.19 g/cm^3) and high porosity (>50%) (Watanabe+2019)
- Consistent with **thermally metamorphosed CM/CI**.
  - Extremely low reflectance (1.9% in VIS-NIR) (Sugita+2019, Kitazato+ 2019)
  - Flat spectra w/o strong 0.7μm absorption band (Cb type) (Sugita+2019)
  - Weak but significant OH band (Kitazato+2019)



Sugita+2019



Kitazato+2019



The average boulder size on Ryugu is ~ **3m** (Sugita+2019 Sci)

Much larger than ~**cm** expected from pre-arrival thermal inertia observation

150-300s $Jm^{-2}s^{-0.5}K^{-1}$ (Müller+2017A&A)

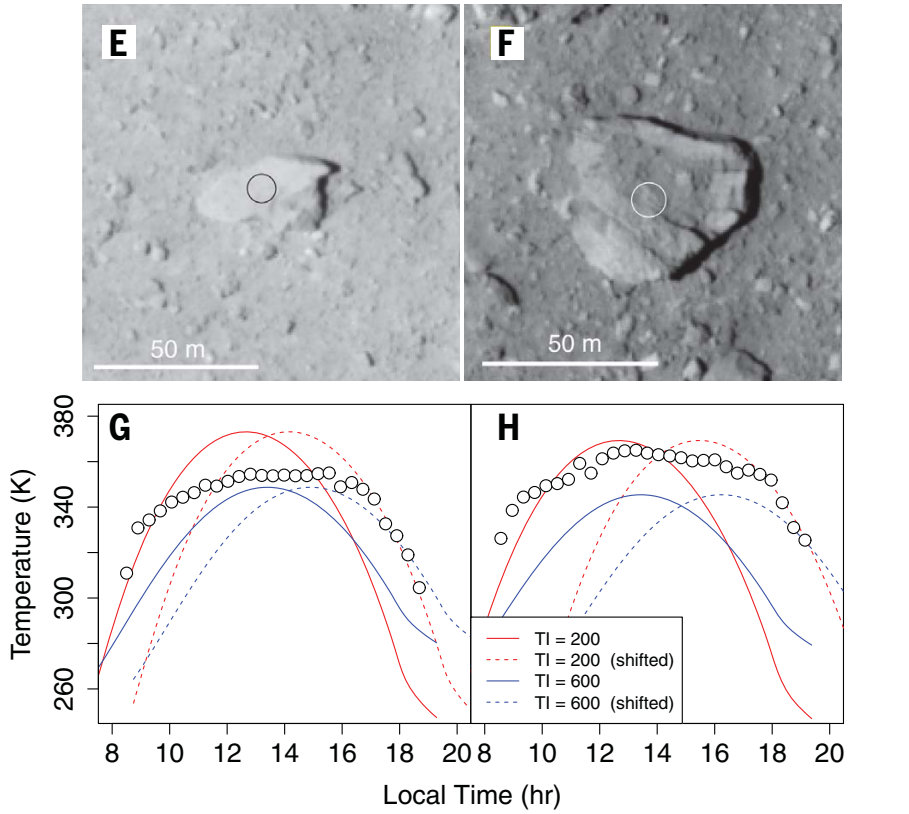
0.9 km

Thermal properties of Ryugu

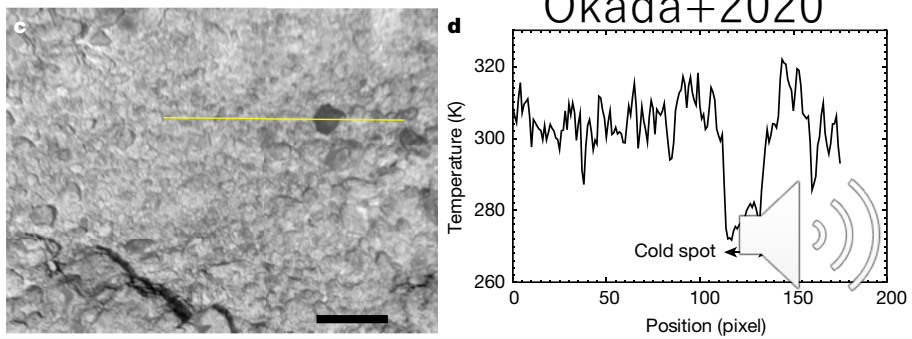
- Thermal inertia is ~300 $Jm^{-2}s^{-0.5}K^{-1}$
  Consistent with **~cm size pebbles**.
  (Sugita+2019 *Science*, Okada+2020 *Nature*, Shimaki+2020 *Icarus*)
- No significant difference in thermal inertia between regolith and boulders.
- There are “cold boulders”(i.e., low porosity). But they are extremely rare
  (Okada+2020 *Nature*).
- ~300 $Jm^{-2}s^{-0.5}K^{-1}$ leads to 0.2-0.28 MPa of tensile strength (Grott+2019)

=> Ryugu is made of large high-porosity boulders.

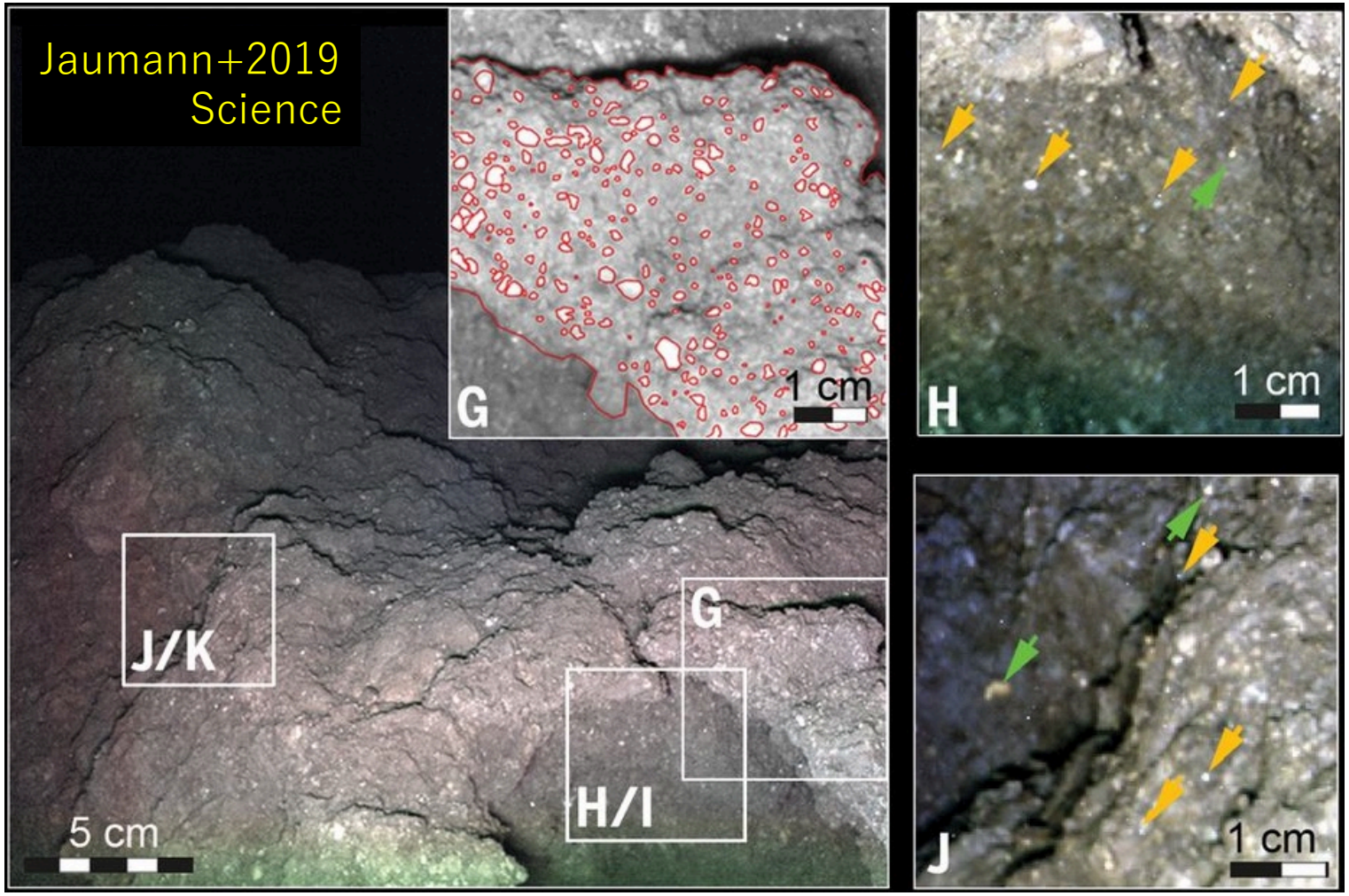
Sugita+2019

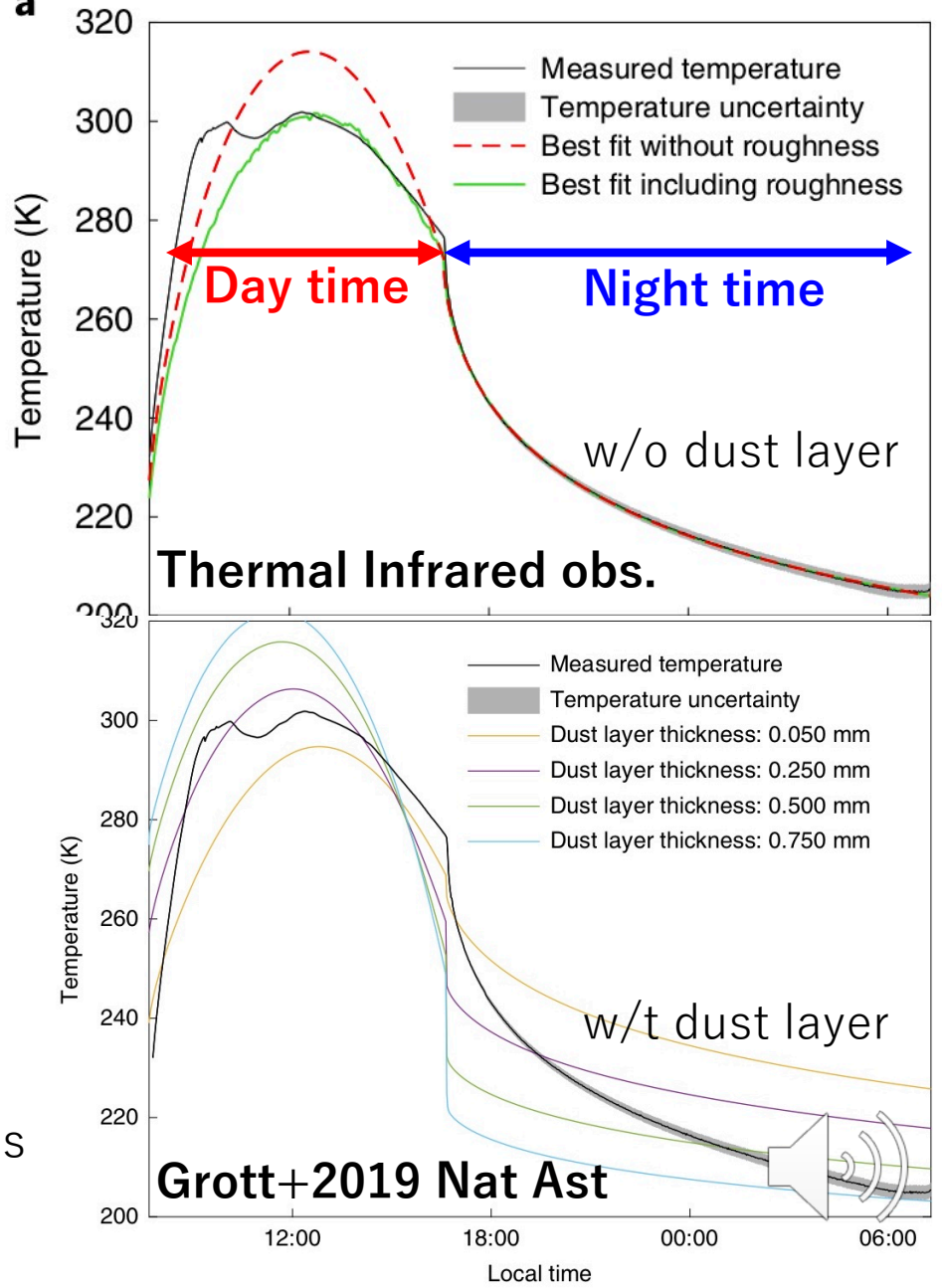


Okada+2020



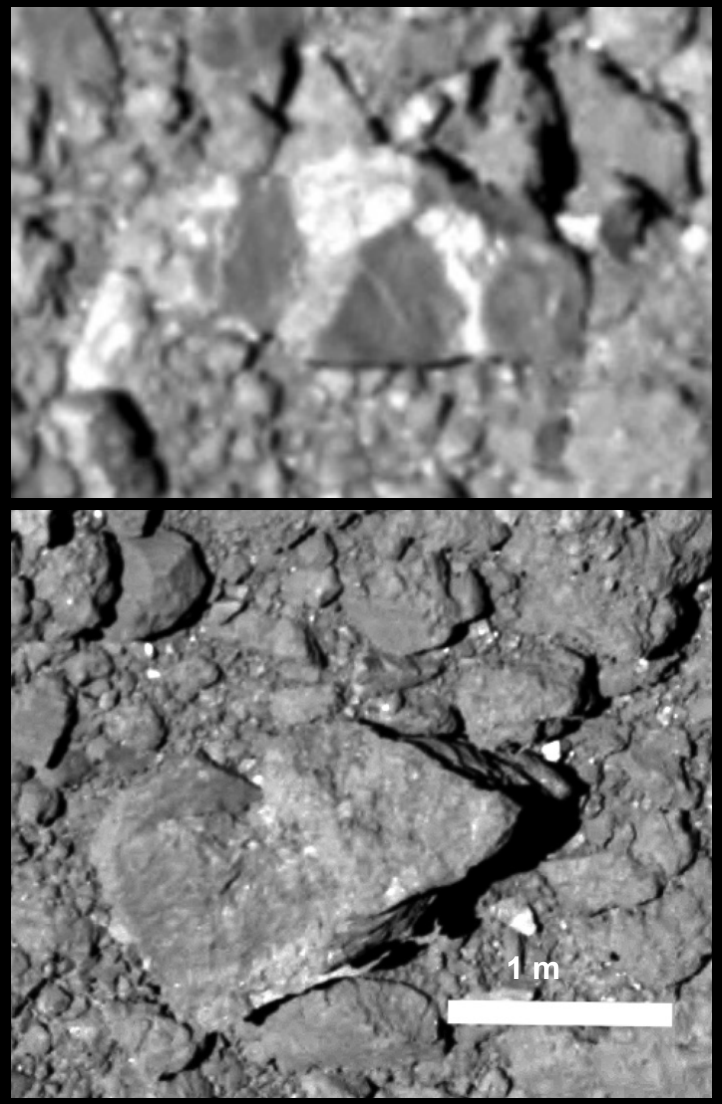
MASCOT's *in situ* measurements!



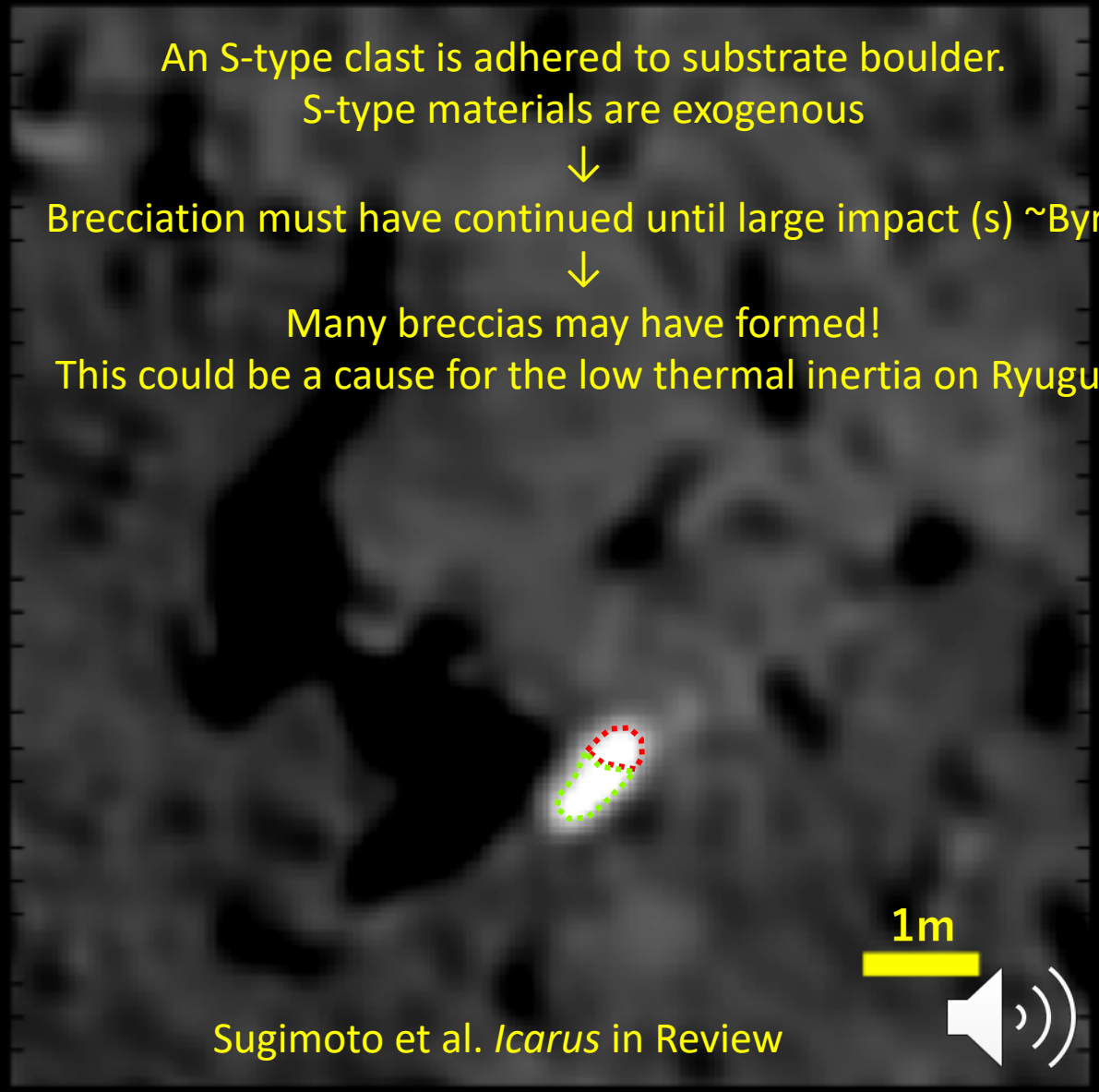


- Morphologies are similar between sub-mm-scale and m-scale images
- Lot of mm-scale inclusions in boulders => **No thick dust layer!**

Breccias on Ryugu



Sugita et al. (2019)



Sugimoto et al. *Icarus* in Review

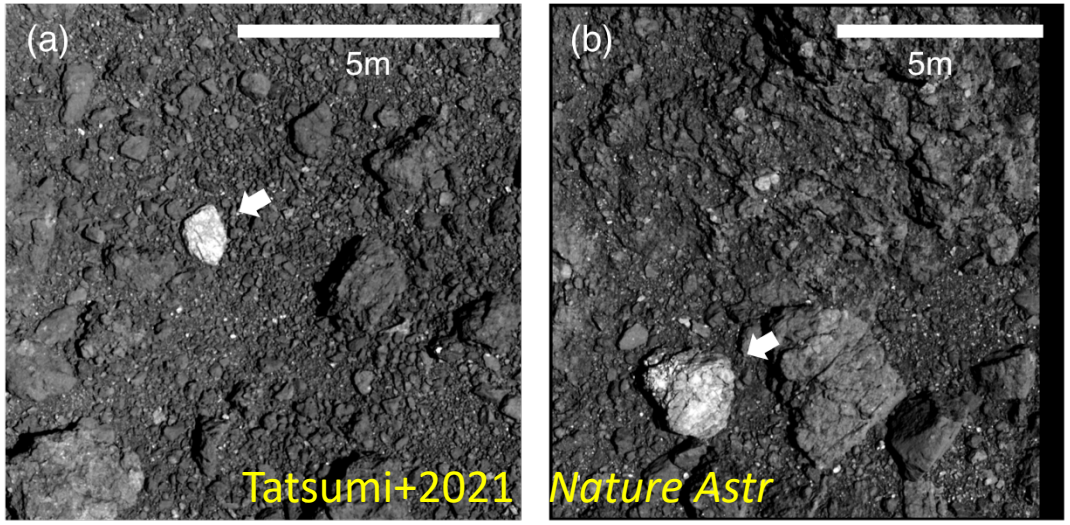
Conclusions

- **Ryugu's spectral properties are consistent with thermally metamorphosed carbonaceous chondrites.**
- **Bulk density 1.19 g/cc is much lower than any carbonaceous chondrites.**
  ➡ High porosity >50%
- **A great gap between grain size (~cm) estimated from thermal inertia and actual average grain size (~3 m).**
  ➡ Ryugu is covered with large high-porosity boulders.
- **No thick dust layer on boulders.**
  ➡ Boulder bulk thermal inertia must be low.
- **Many pieces of evidence for breccia on Ryugu.**
- **Breccia structure may be a significant cause for Ryugu's low thermal inertia.**

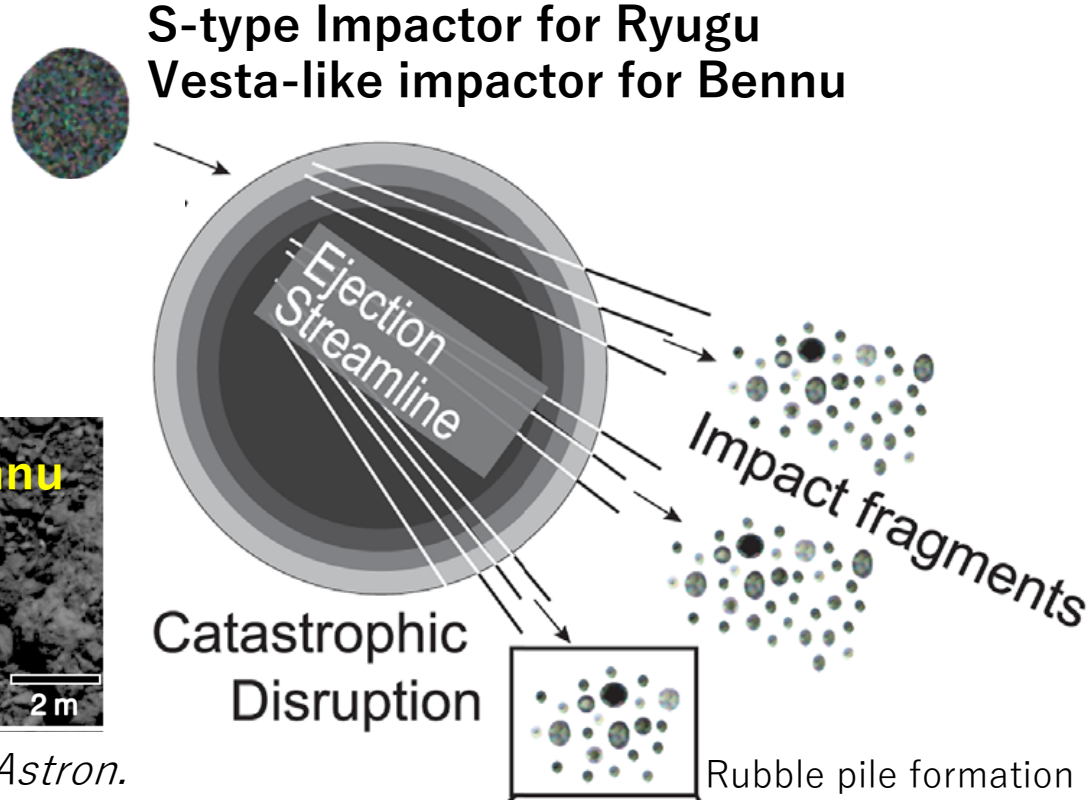
➡ **Breccia structure may be an important factor to consider for planetary defense of low-albedo asteroids.**

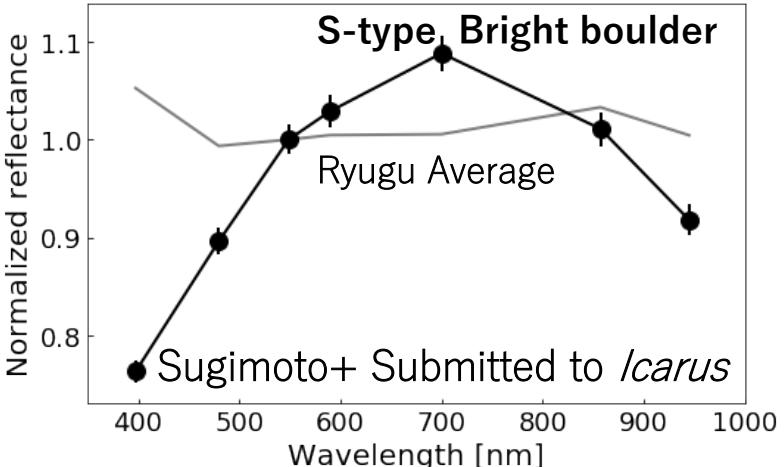
Bright boulders (BBs) on Ryugu and Bennu

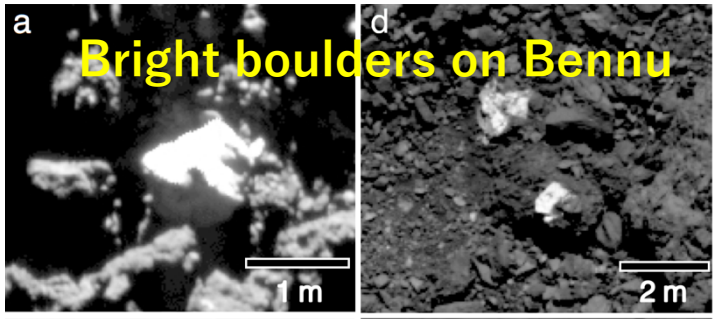
- Ryugu is uniformly dark. (Sugita+2019 *Science*).
- Tatsumi+(2021 Nat. Geo) found 21 BBs. Most have **C-type** spectra; some have **S-type** spectra.
- **S-type BBs are likely exogenic** but too large to accrete on Ryugu after becoming current size.



➔ S-type BBs are probably fragments from impactor(s) to Ryugu's parent body.







DellaGiustina+2021 *Nature Astron.*