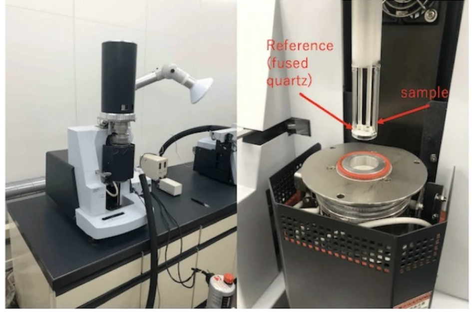
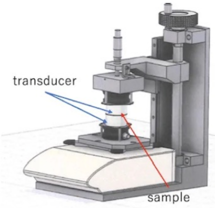
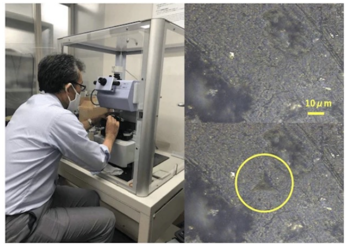
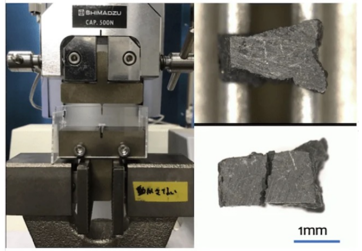
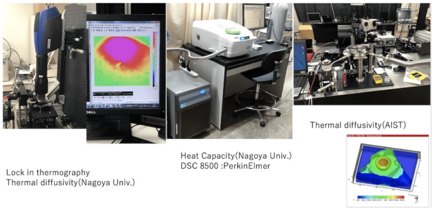


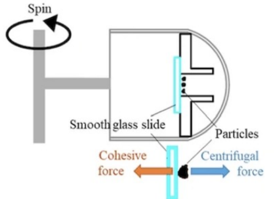


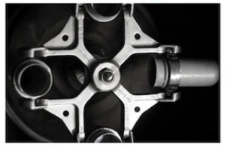




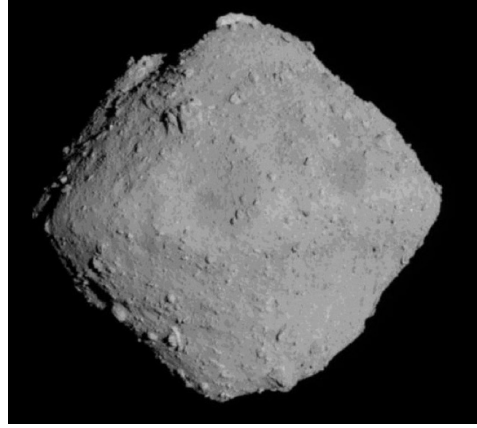
What if Ryugu Hits on Earth?





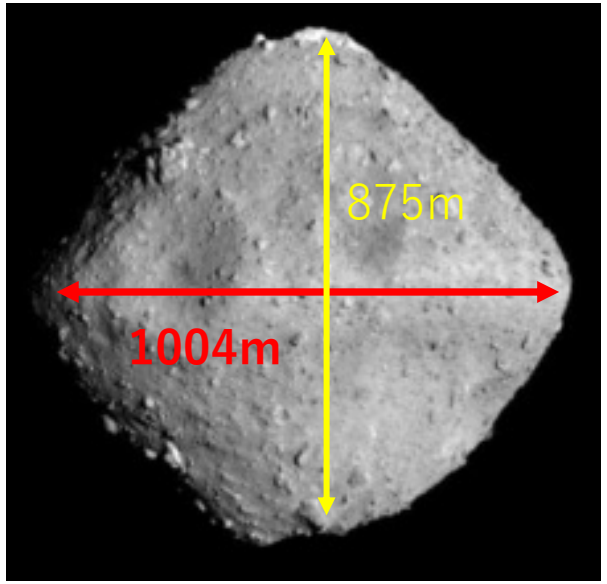


Satoshi Tanaka[1], Koji Wada[2], Masatoshi Hirabayashi[3],
Yuya Mimasu[1], Makoto Yoshikawa[1], Takanao Saiki[1],
Satoru Nakazawa[1], Yuichi Tusda[1]
([1]JAXA, [2]Chiba Institute of Technology, [3]Auburn University)



- The Hayabusa2 mission conducted detailed remote sensing exploration for more than one year and obtained information about the surface and interior of the planet.
- In addition, Hayabusa2 successfully carried out two touchdown operations, collected more than 5g of samples, and successfully brought them back to Earth.
- Much of this information was also available on Planetary Defense.

Remote sensing observations..



- Shape : Top shape :0.377km^3(Watanabe et al.,2019)
- Bulk density :1190kg/m^3 ->High porosity (>50%)

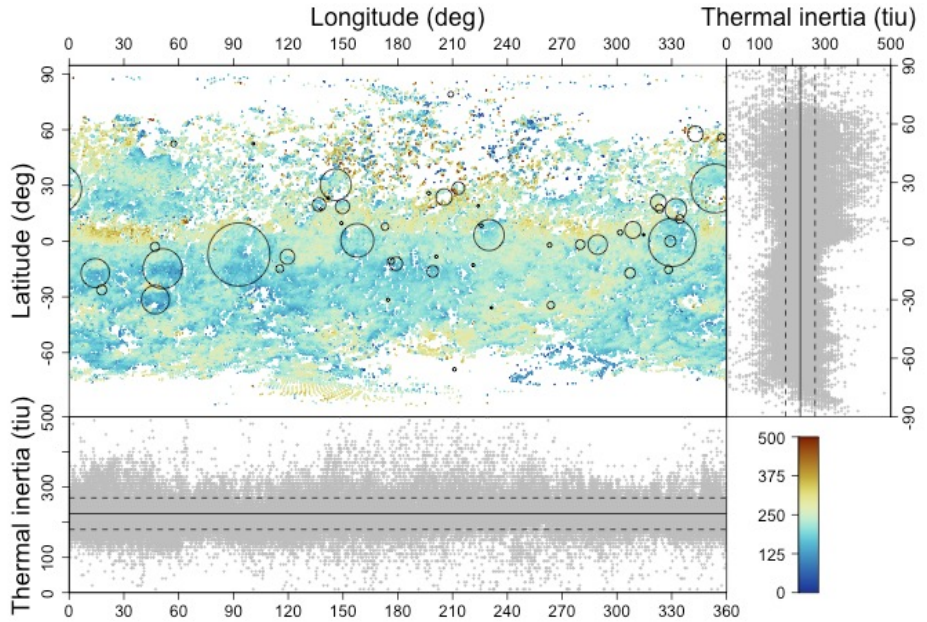
  (Watanabe et al.,2019)
- Structure: Rubble pile (fragment size: unknown)

- Thermal Inertia: 225 ± 45 (J/m^{2}Ks$^{1/2}$)

  (Shimaki et al.,2020)

  ->tensile strength:0.2-0.3(MPa)

  (Grott et al.,2019)



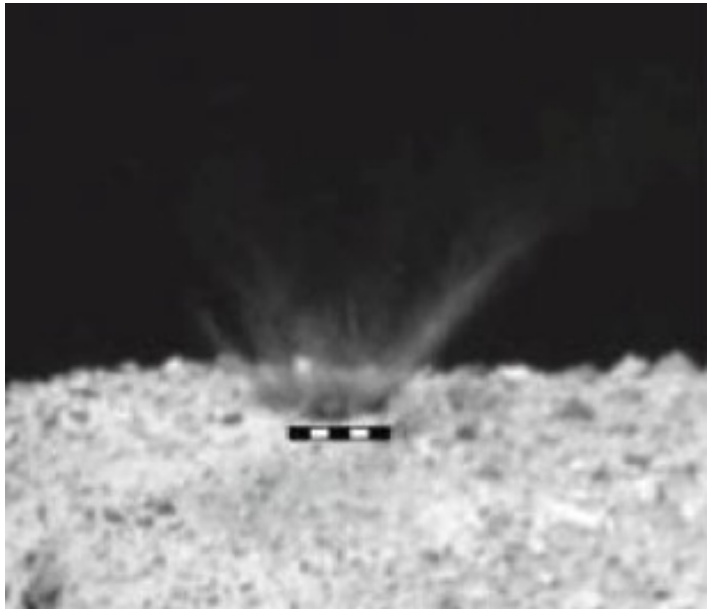
Shimaki et al.,2020

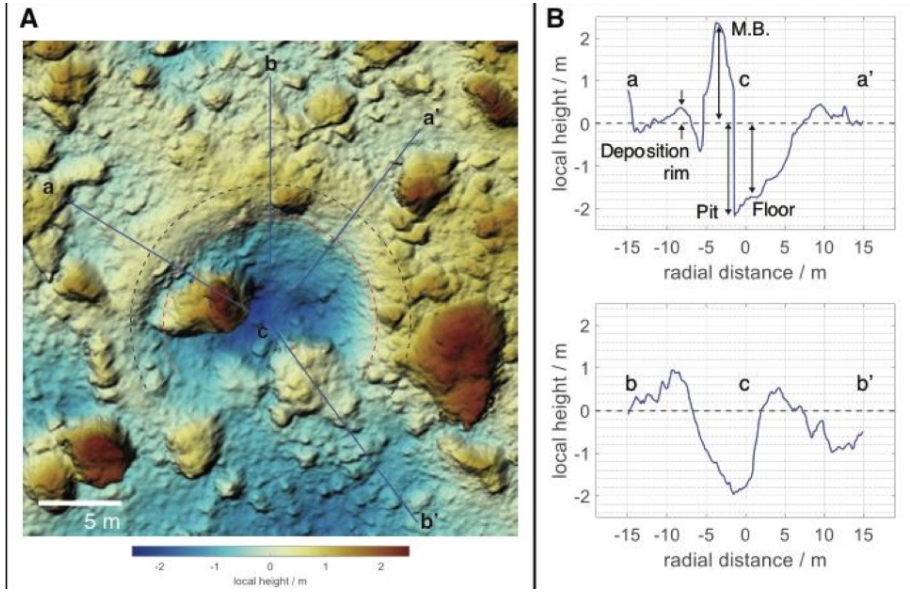
Remote sensing observations..

- Small Carry on Impact experiment (SCI)

  ->A 2kg copper object was impacted at a 2 km/s, creating a crater of about 20 m in diameter.

->Cohesion strength:130-300Pa

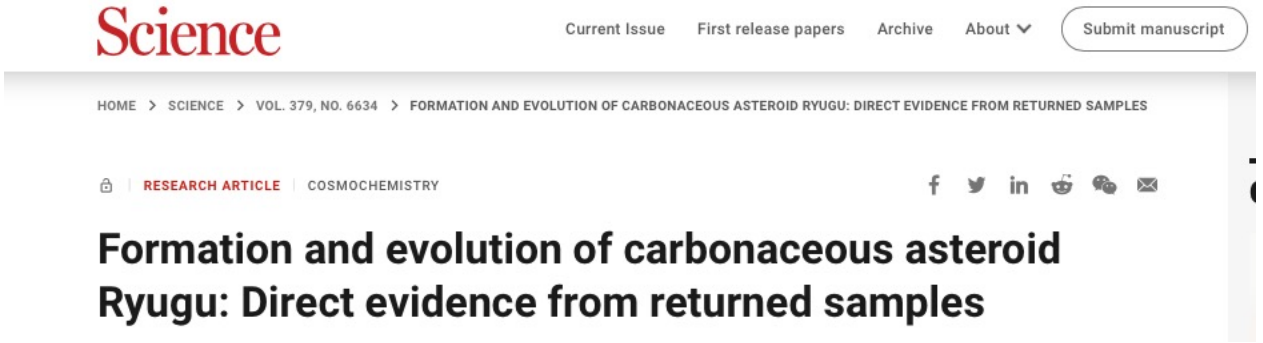




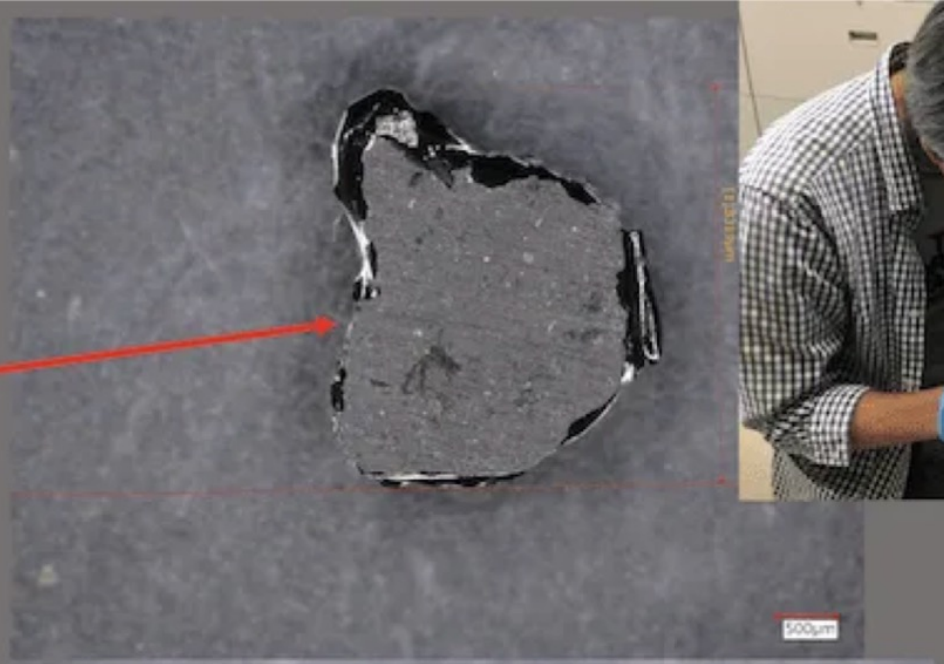
(Arakawa et al.,2020)

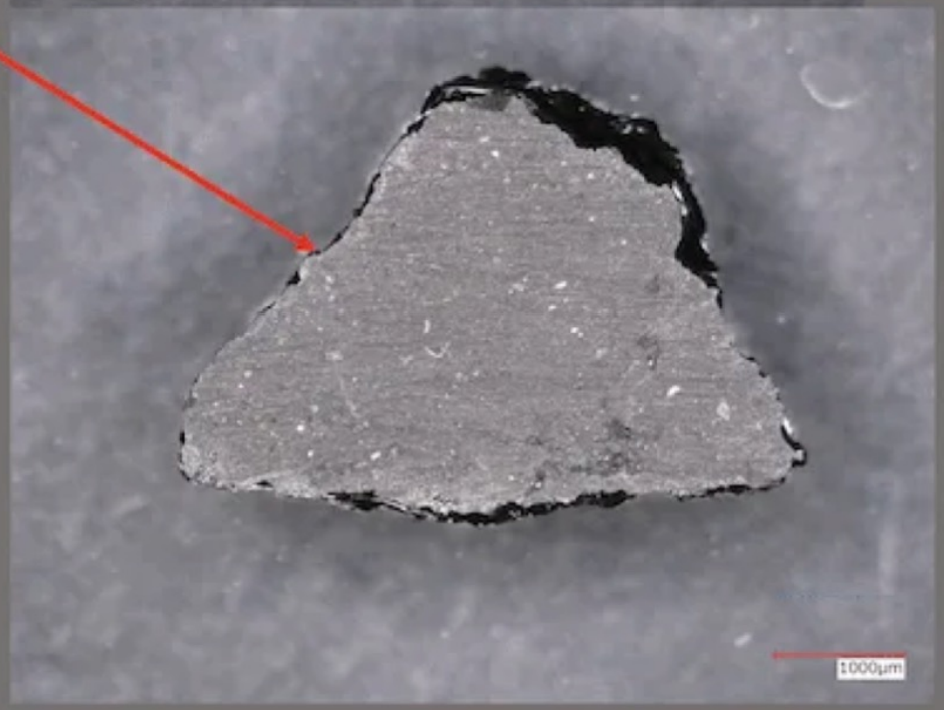
Physical Properies of Ryugu Sample

- Sixteen physical properties were measured on the third-largest fragment in the return sample.
- Among these, seven mechanical properties were measured and fracture strength tests were conducted.
- The measured values are summarized in Nakamura et al. (2022)

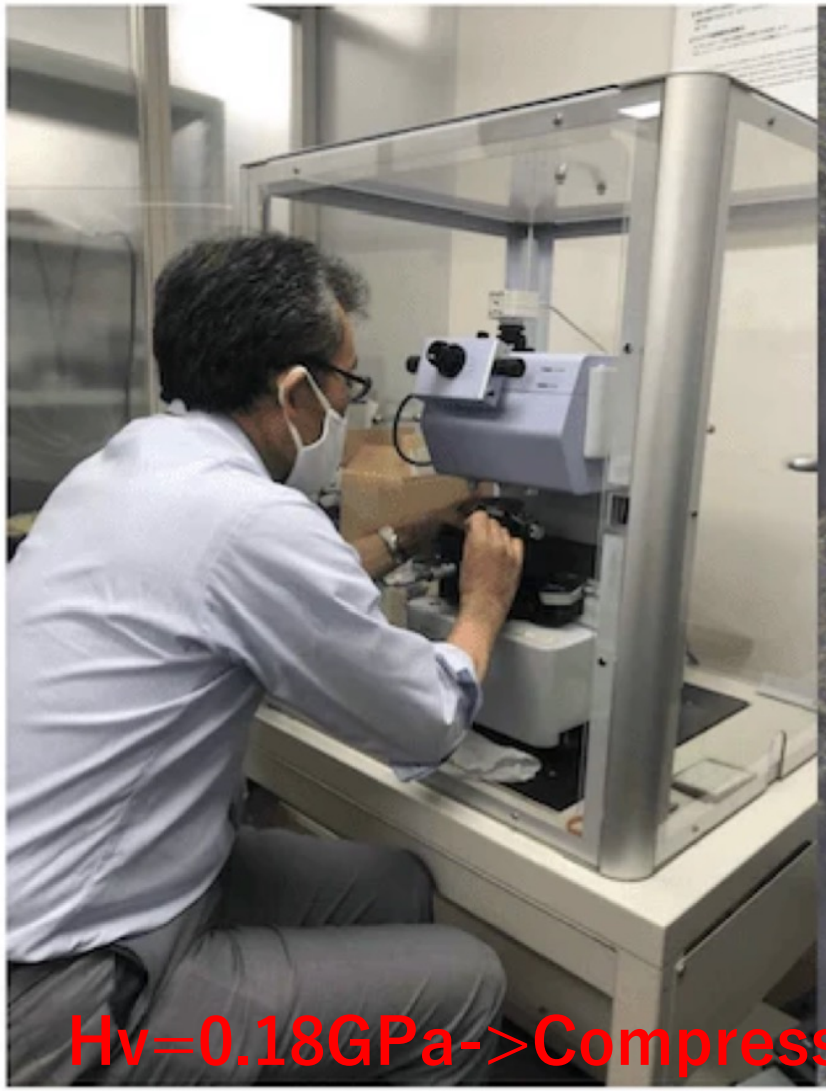


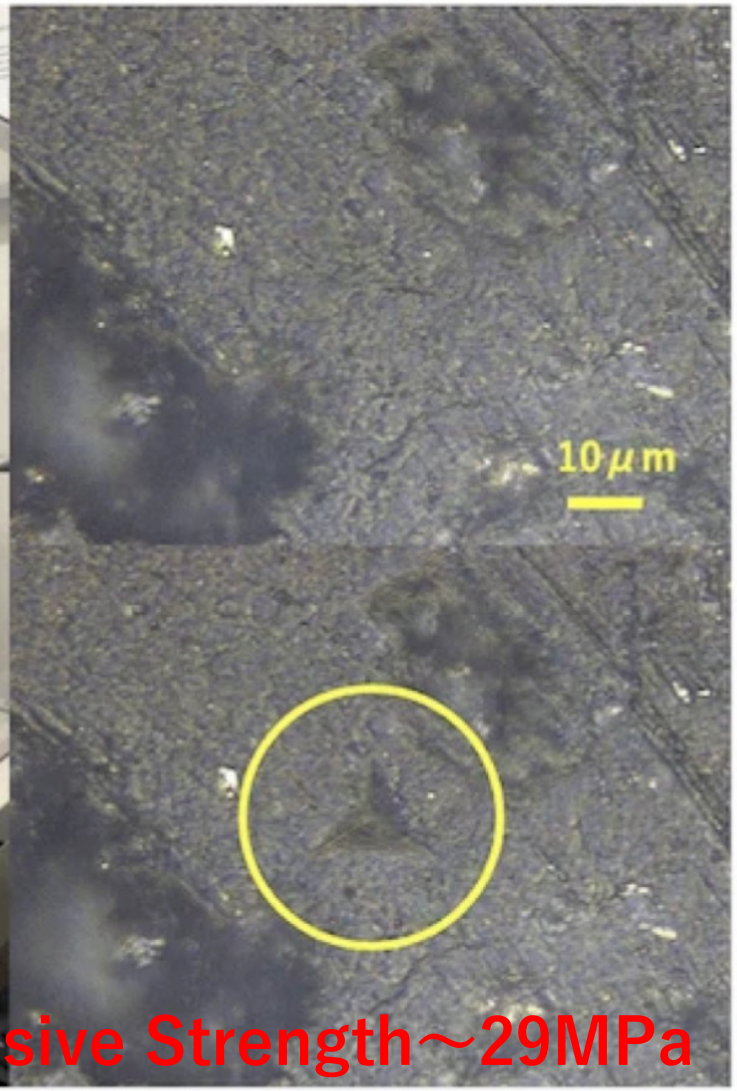

C0002
sliced sample No.3
sliced sample No.4
M=94mg
ρ =1.82g/cc
Porocity 1.7%
1 mm


500μm

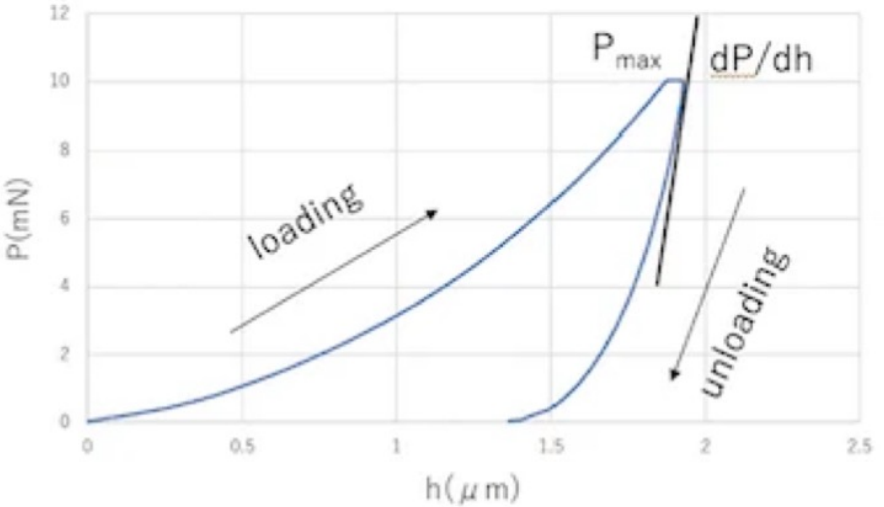

1000μm

Hardness measurement (ISAS/Shimadzu Co.)





Hv=0.18GPa->Compressive Strength～29MPa

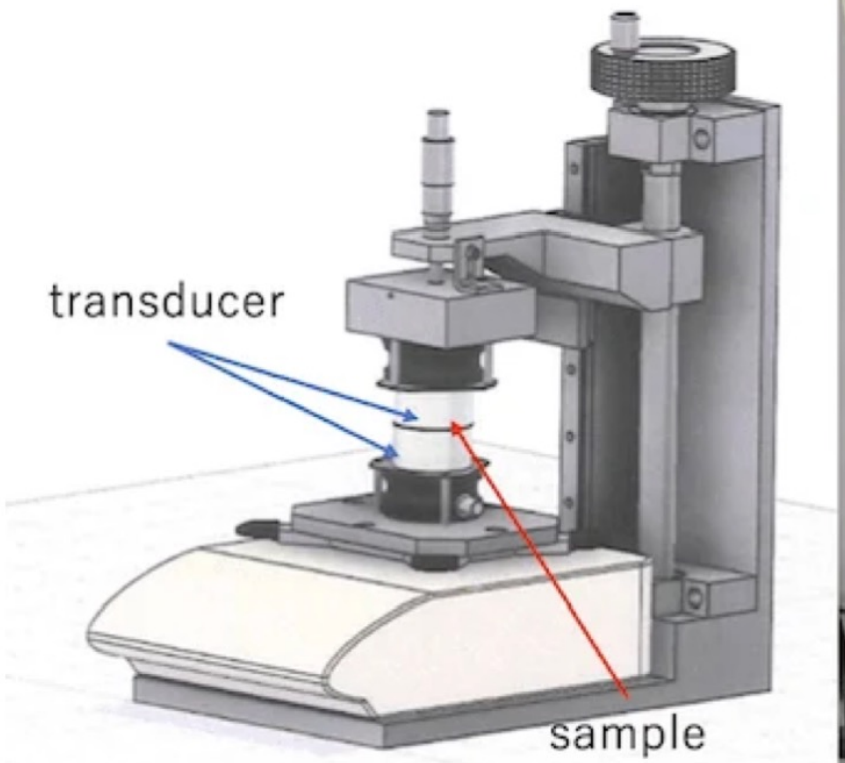


$$H = P_{max}/A$$

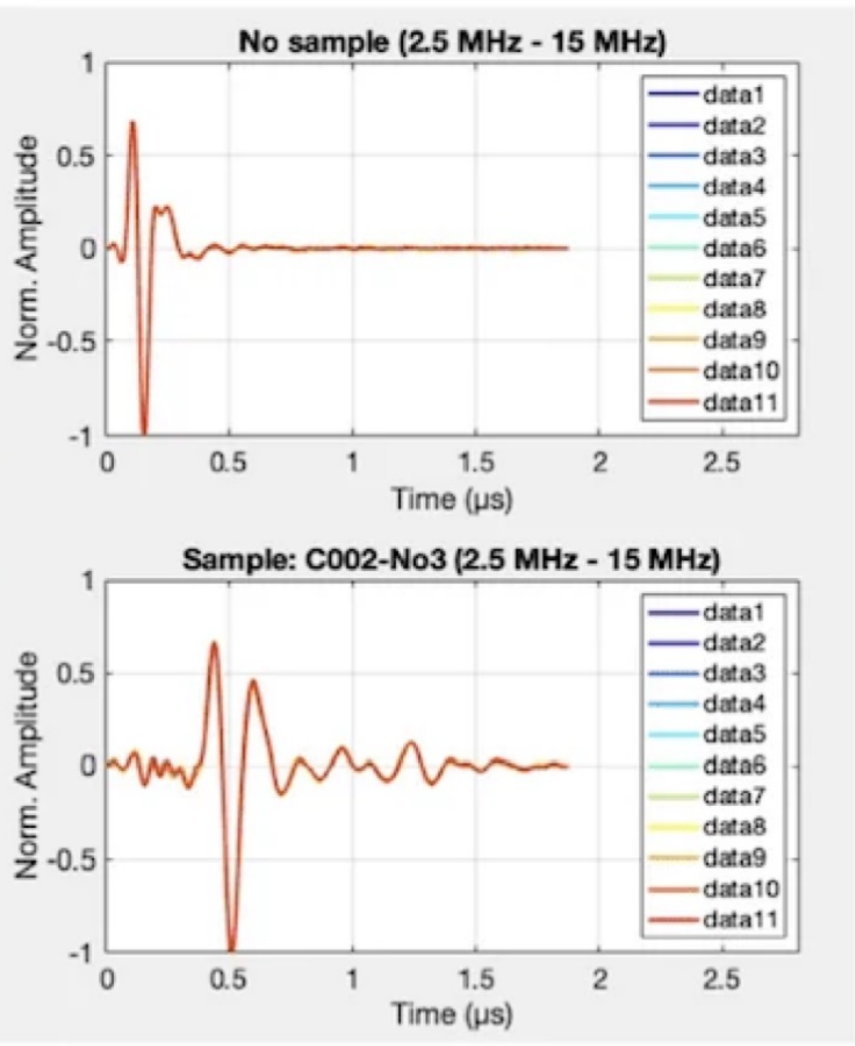
H :Hardness
A :projected contact area

Shimadzu DHU-211 Dynamic Ultra Hardness Tester

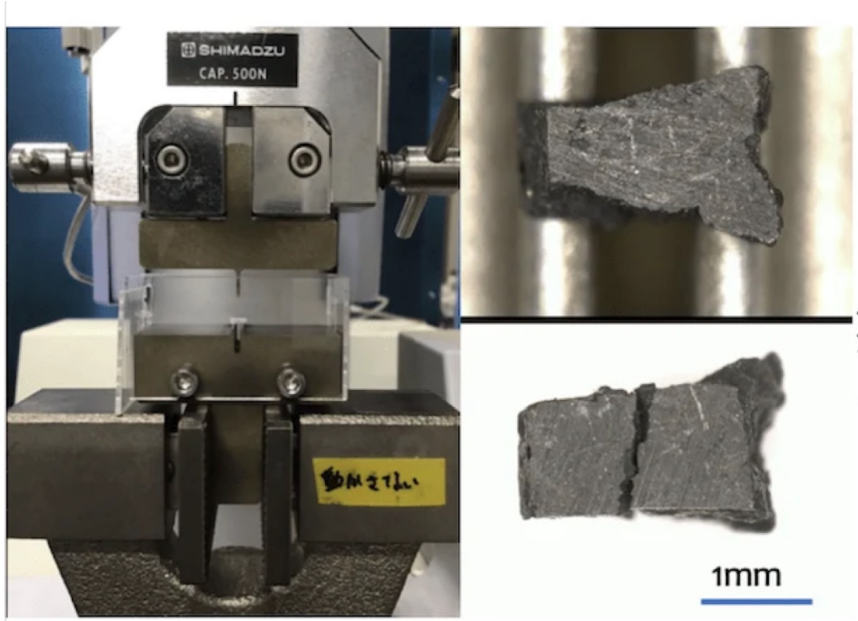
Elastic velocity measurement

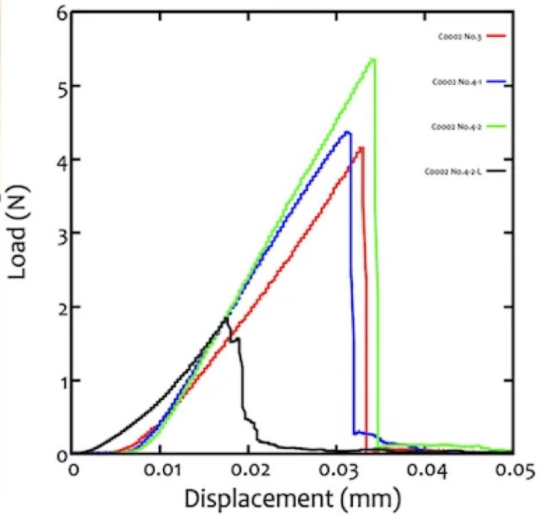


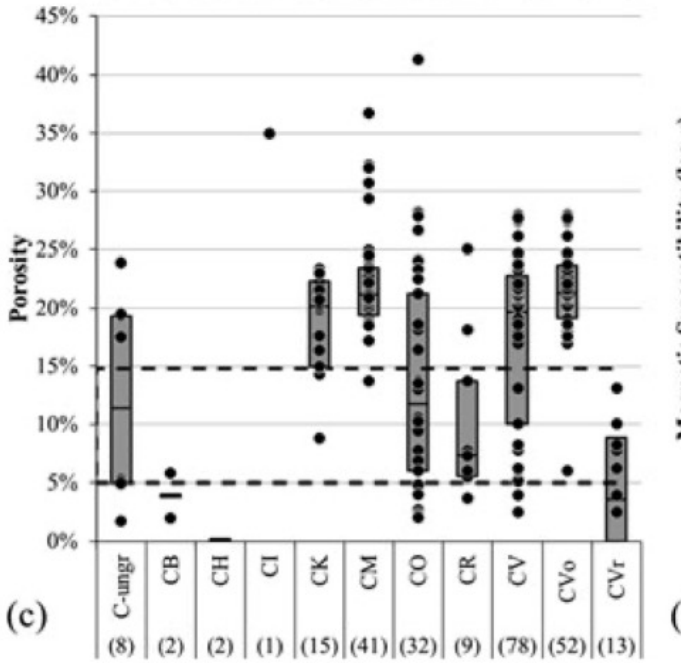
Vp=2.08km/s
Vs=1.37km/s



Bending Flexural Test (ISAS/CIT)







Macke et al.,(2011)

4.9MPa～Tensile Strength

	Prediction	Measured	
Compressive strength of rock	15–30	30	MPa
Tensile strength of rock	< 1	1-10	MPa

Wate et al.,(2018)　　This study

Table 1. Summary of physical property measurement of Ryugu samples.

Mechanical Properties	value	error	unit	condition	mesaured sample(s)
compressive hardness	0.18	0.10	GPa	ambient	#C0002 plate 3
Young's modulus	5.3	1.6	GPa	ambient	#C0002 plate 3
bending strength	4.9	1.9	MPa	ambient	C0002 plate 3 and 4
longitudial velocity	2.08	0.13	km/s	ambient	*avg. of C0002 plate 3 and 4
shear velocity	1.37	0.15	km/s	ambient	*avg. of C0002 plate 3 and 4
thermal expansivity	2.6×10^{-5}	2×10^{-6}	/K	210-400K, nitrogen gas	C0002 plate 3
cohesive force	0.17	0.02	μN	ambient	$C0002 plate 4
Thermal properties					
heat capacity(298K)	865	16	J/kg/K	213-373K, nitrogen gas	avg. of A0026 and C0002 plate4
thermal diffusivity	3.2×10^{-7}	0.3×10^{-7}	m^2/s	300k, vacuumed	avg. of C0002 plate 3 and 4
Electrical properties					
resistivity	2.5×10^{6}	0.3×10^{-6}	ohm・m	300k, vacuumed	avg. of C0002 plate 3 and 4
relative permittivity	6.8	0.8	-	300k, vacuumed	avg. of C0002 plate 3 and 4
Magnetic properties					
susceptibility	8.39×10^{-5}	4.0×10^{-6}	m^3/kg	300 K, dc, ac (1-1000 Hz)	avg. of C0002 and A0026
saturation magnetization	11.6	5.1×10^{-3}	Am^2/kg	300 K	avg. of C0002 and A0026
saturation remanence	1.05	6.3×10^{-3}	Am^2/kg	300 K	avg. of C0002 and A0026
coercivity	12.2	9.3×10^{-2}	mT	300 K	avg. of C0002 and A0026
coercivity of remanence	61.3	4.1×10^{-1}	mT	300 K	avg. of C0002 and A0026

Nakamura et al.,(2022)

In brief, the values obtained were generally consistent with the physical properties of CI chondrites.

“What if Ryugu Hits on Earth?”

- Earth impact effects were analyzed by applying our measured mechanical property data to Collins et al., (2005).

Meteoritics & Planetary Science 40, Nr 6, 817–840 (2005)
Abstract available online at http://meteoritics.org

Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth

Gareth S. COLLINS,[1*] H. Jay MELOSH,[2] and Robert A. MARCUS[2]

PURDUE UNIVERSITY

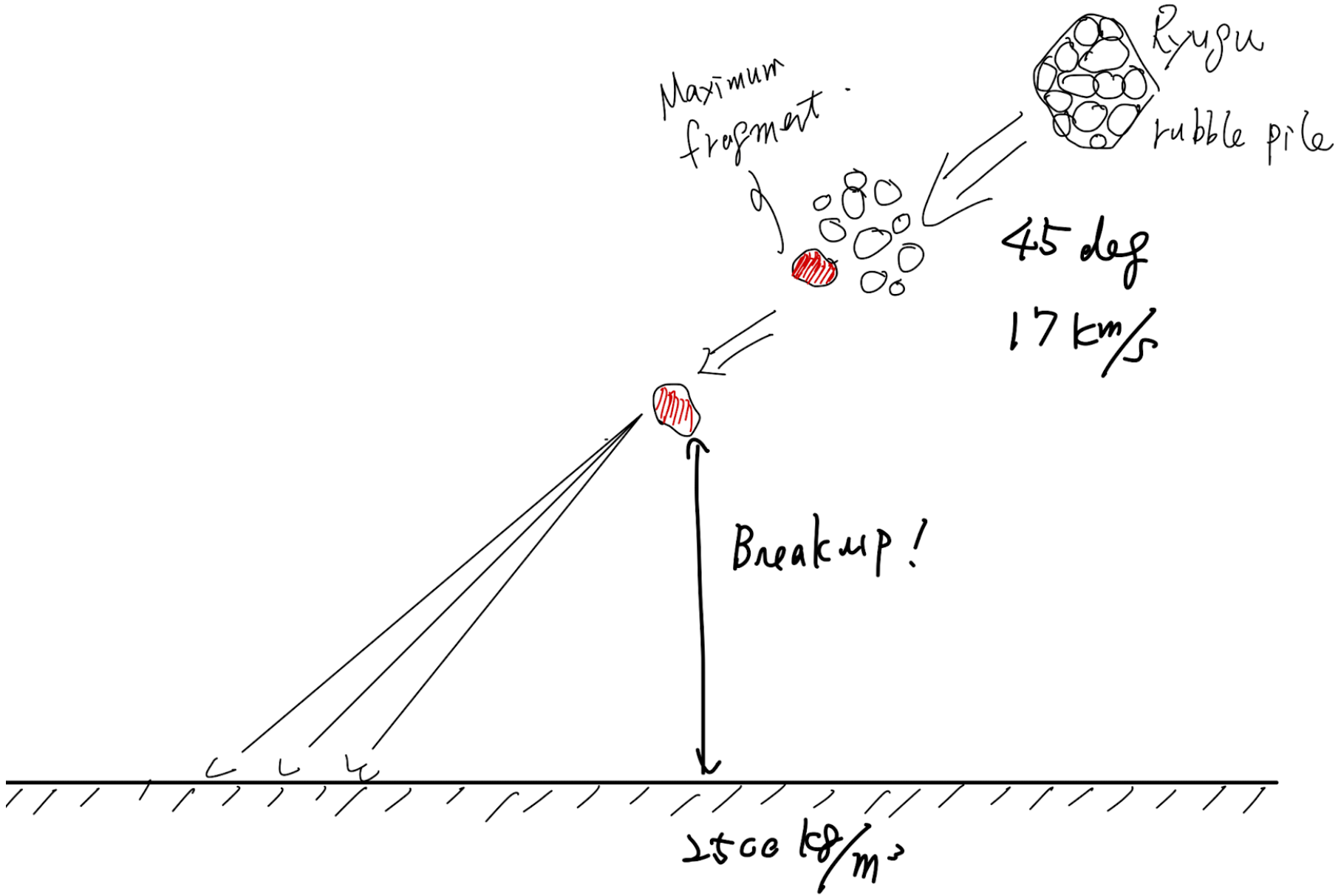
Earth Impact Effects Program

Robert Marcus, H. Jay Melosh, and Gareth Collins

Please note: the results below are estimates based on current (limited) understanding of the impact process and come with large uncertainties; they should be used with caution, particularly in the case of peculiar input parameters. All values are given to three significant figures but this does not reflect the precision of the estimate. For more information about the uncertainty associated with our calculations and a full discussion of this program, please refer to this article

https://impact.ese.ic.ac.uk/ImpactEarth/ImpactEffects/

model setting



Summary of physical parameters of the Impactor

	Density	tensile strength
	kg/m^3	MPa
Remote sensing	1200	0.2-0.3
Sample measurement	1800	5
Empirical	1200-1800	0.019-0.057

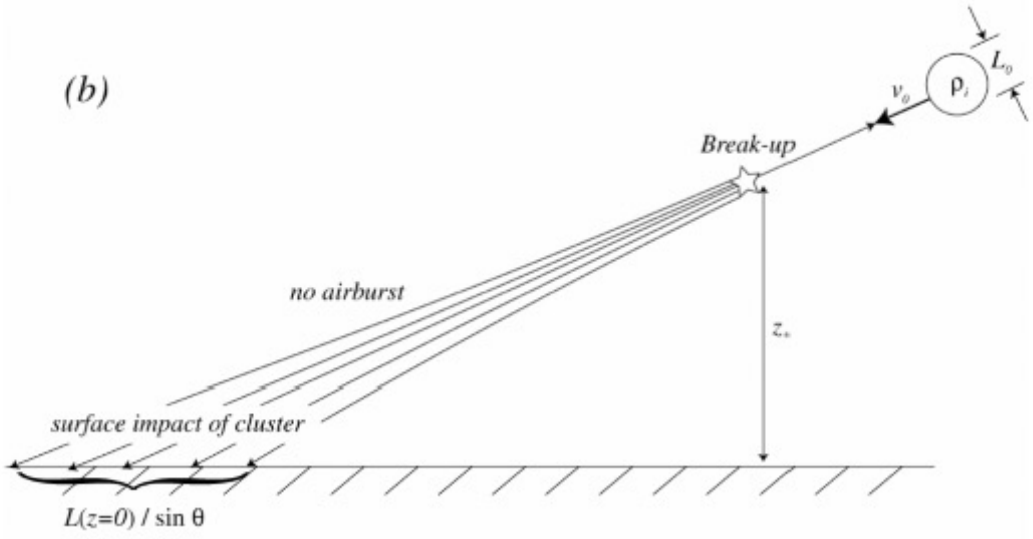
"Empirical" (Collins et al.,2005); $\log_{10} Y_i = 2.107 + 0.0624\sqrt{\rho_i}$

Impact size=The maximum rubble fragment size ->unknown

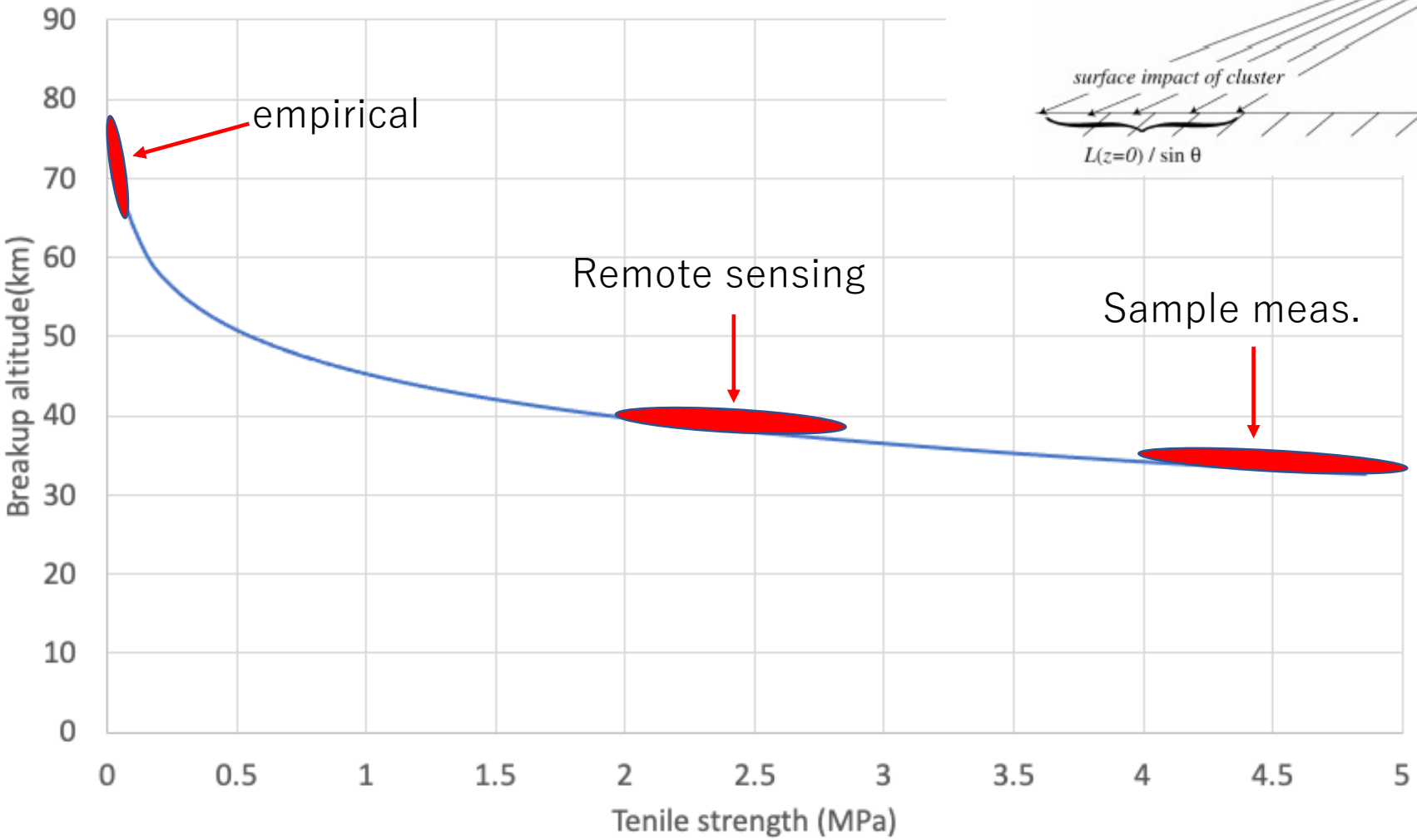
＊）The cohesion force between fragments is assumed to be zero based on the results of the SCI experiment.

Breakup altitude

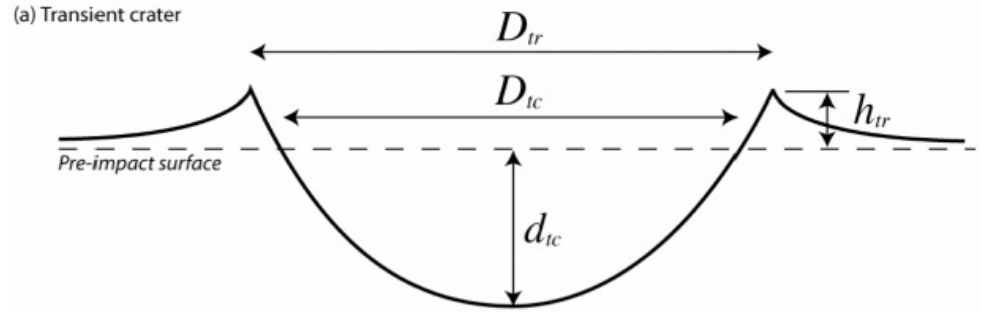
Impactor density :1200-1800kg/m3
Impact velocity=17km/s
Incident angle =45degrees

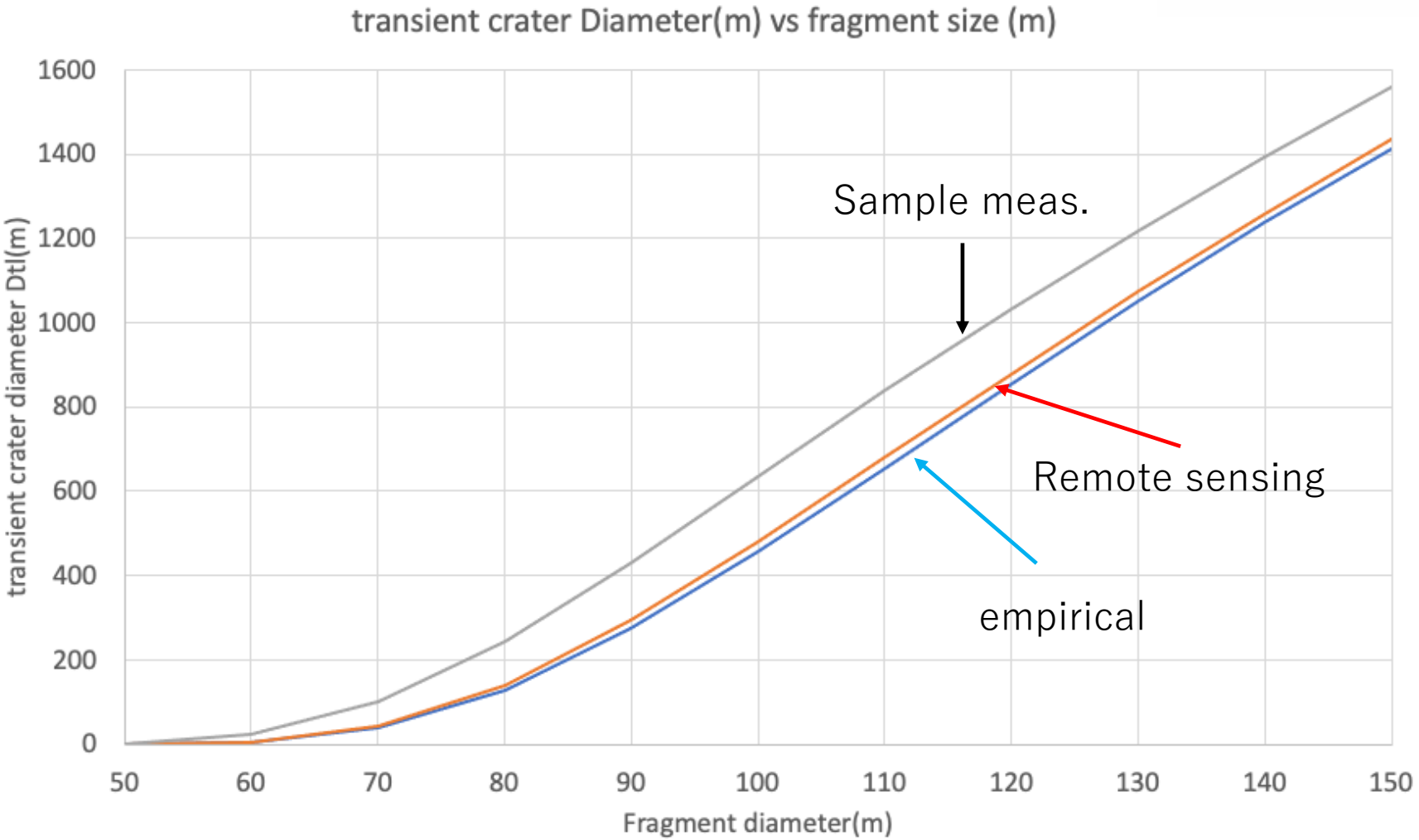


Collins et al.,(2005)



Impact velocity=17km/s
Incident angle =45degrees
Impactor density=1800kg/m^3
Target density =2500kg/m^3





Collins et al.,(2005)

Conclusion

- Ryugu's detailed remote sensing survey and sample analysis have revealed the mechanical properties of the asteroid for the first time.
- Tensile strength may be more than two orders of magnitude greater than empirically estimated values, which could alter the impact effect on Earth.
- The returned sample is in the process of completing its initial analysis and is not yet statistically complete. The sample is still sufficiently voluminous that future measurements are expected.
- Ryugu is a rubble pile structure, but the maximum size of the rubble is unclear. Internal structure exploration will be important in the future to more precisely assess the impact on the Earth.