Science Return from Hayabusa

International Symposium Marco Polo and other Small Body Sample Return Mission

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Portoferraio, Isola d'Elba, Italy

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Itokawa is a tiny asteroid, but we have leaned a lot of interesting facts.

In the followings, we show the nature of Itokawa that we revealed up to now.

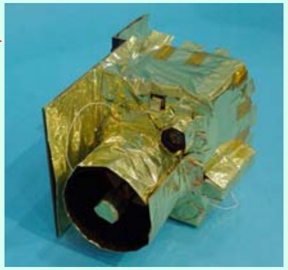
Remote Sensing Instruments of Hayabusa

•Multi-Spectral Telescopic Imager (AMICA)

CCD viewing angle 5.7° with 8 band-pass filters
(About 1500 still images obtained)

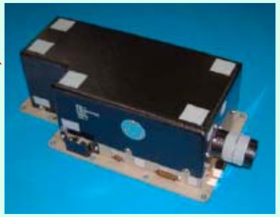
•Laser Altimeter (LIDAR)

Measurement accuracy of 1m at 50m altitude
(1,670,000 hits obtained)



•Near-Infrared Spectrometer (NIRS)

64-channel InGaAs detector at wavelengths of 0.8~2.1 micron
Viewing angle 0.1° (6-90m per pixel spatial resolution)
(More than 80,000 spectra obtained)



•X-ray Fluorescence Spectrometer (XRS)

CCD viewing angle: 3.5°, 160eV resolution at 5.9keV
(6,000 spectra from the asteroid surface obtained)

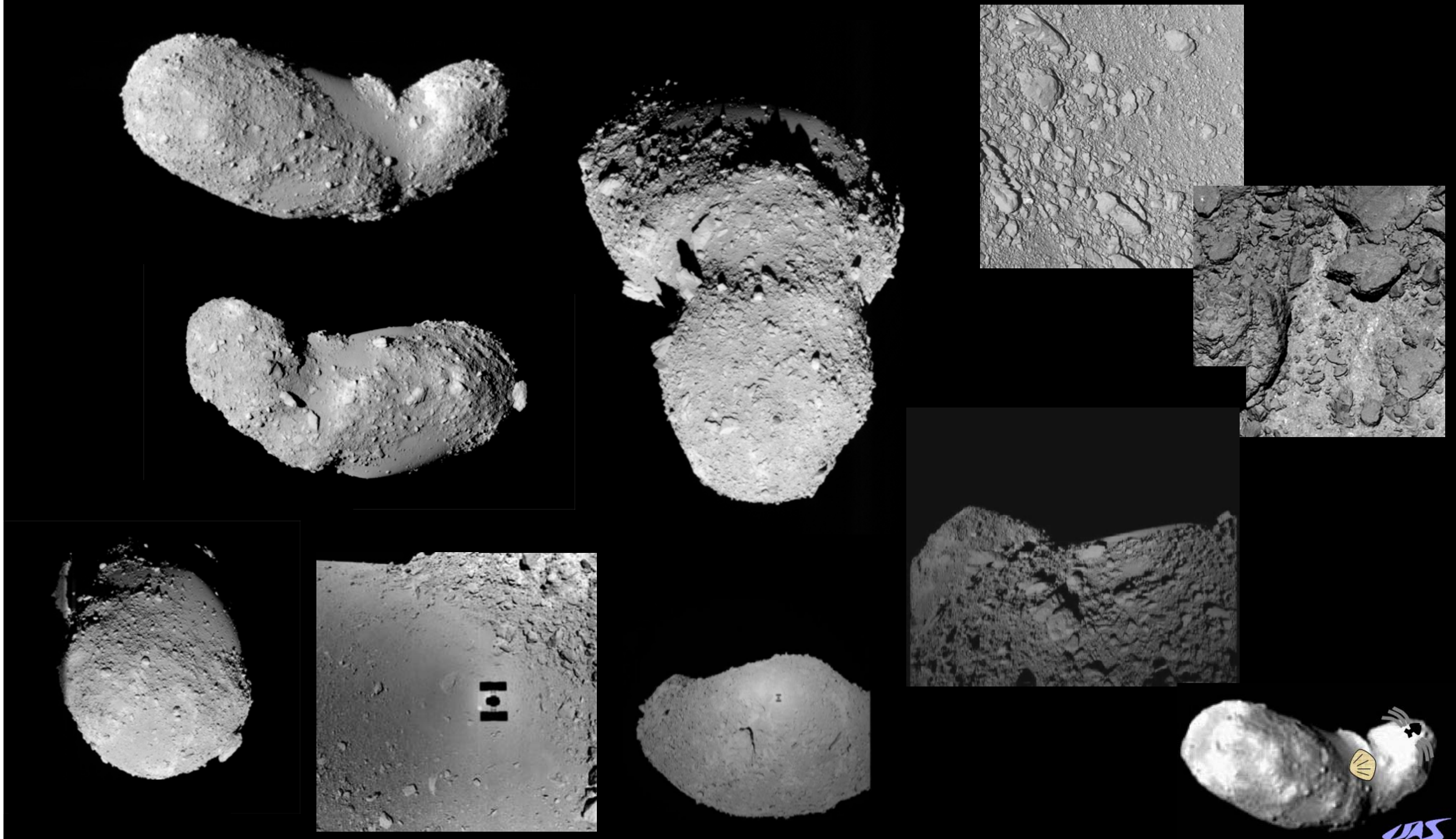
Hayabusa is mainly the technological demonstrator, but it has four scientific instruments above.

AMICA

AMICA

Images

There are lots of images of Itokawa taken by Hayabusa.



AMICA Radiometric Calibration

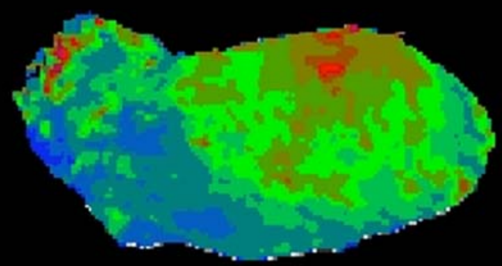
Ishiguro et al. *submitted to Icarus*

- The performance of AMICA was examined, based on both pre-flight and in-flight measurements. We found that
  - AMICA signal is linear with respect to the input signal to an accuracy of <<1% when the signal level is < 3800 DN.
  - the absolute radiance calibration of AMICA v-band (0.55μm) is accurate to within 4% or less,
  - the filter-to-filter precision of the calibrated reflectance is about 1%
  - the pixel-to-pixel precision of the calibrated relative data is 3% or less.
  - The uncertainty of the background zero level is 5DN.
- Using these parameters above and images near opposition, we deduced a geometric albedo of p_v=0.25±0.03, which shows good agreement with that obtained by the ground-based observations (Thomas-Osip et al. 2008).

AMICA

Normal Albedo Map (0.55μm)

Ishiguro et al. *submitted to Icarus*



Now we know the albedo difference for all the surface of Itokawa.

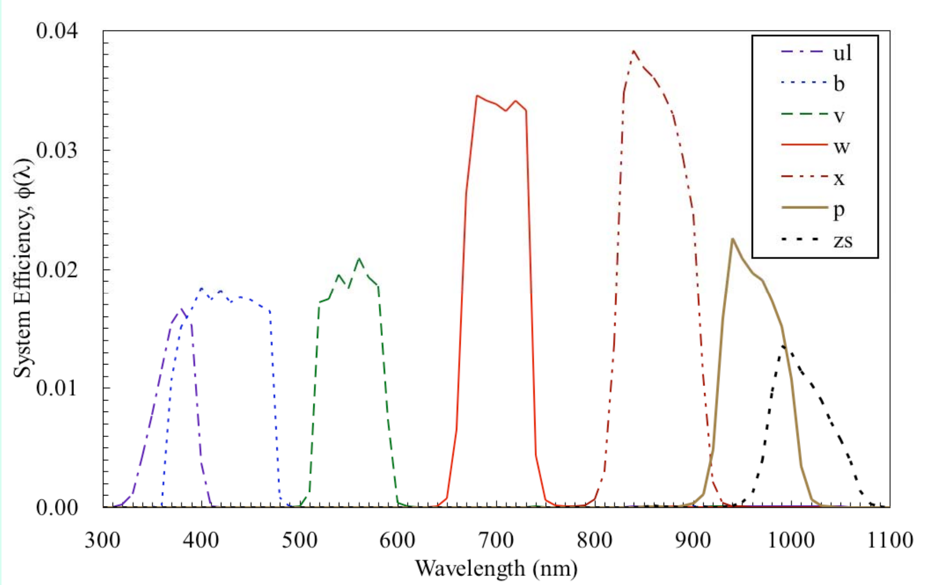
Color Ratio Map

AMICA

Ishiguro et al. *submitted to Icarus*

- It is known that AMICA p-band and zs-band images are contaminated by lights scattered inside the optics. We developed the scheme to subtract the scattered light by determining the point spread functions.

- As the results, we found the correlation between R_w/R_b (the ratio of the w-band intensity to the b-band intensity) and R_p/R_w (the ratio of the p-band intensity to the w-band intensity). In other words, regions with shallower slope between 0.43 μm and 0.70 μm show the deep absorption around 1 μm (e.g. Kamoi crater).

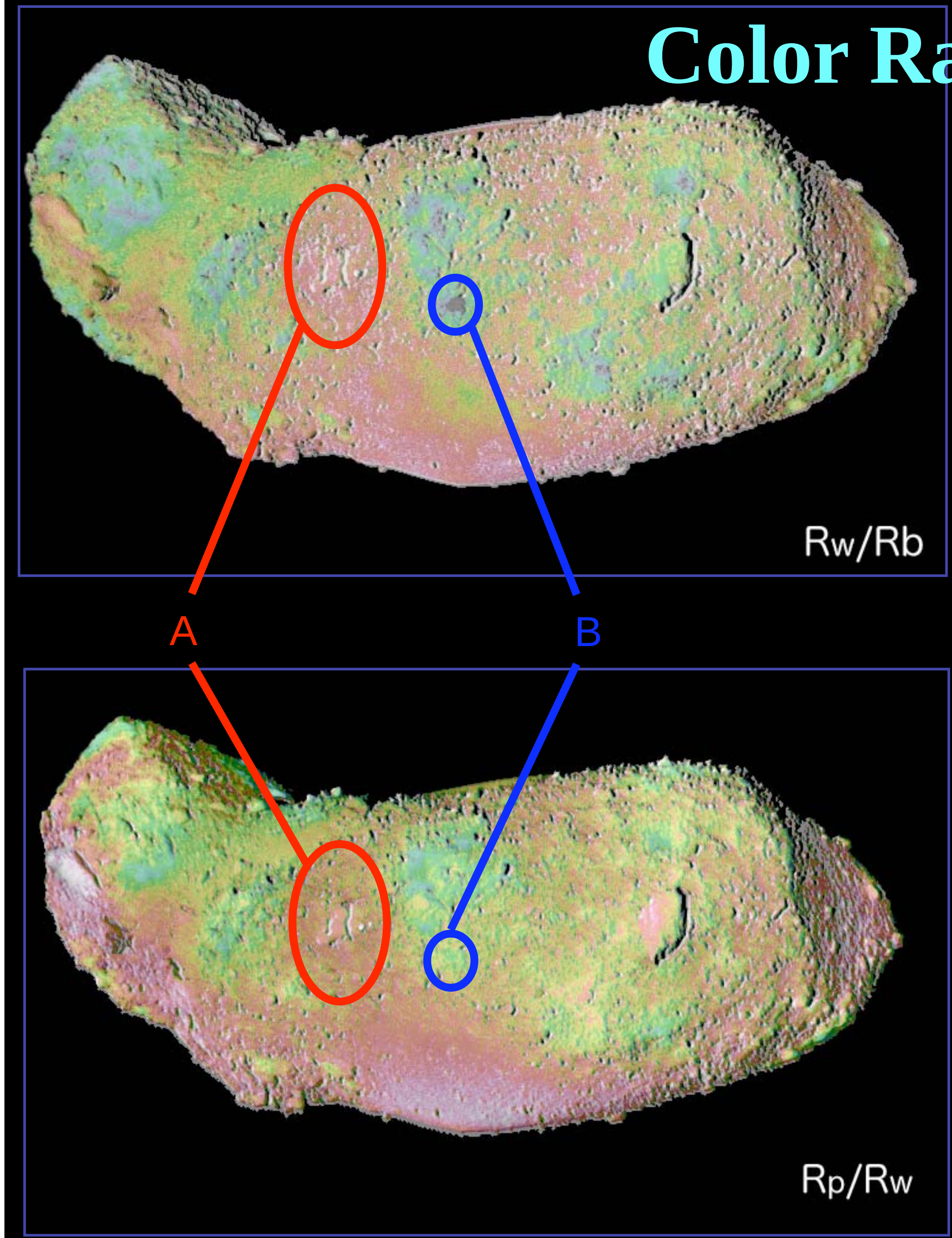


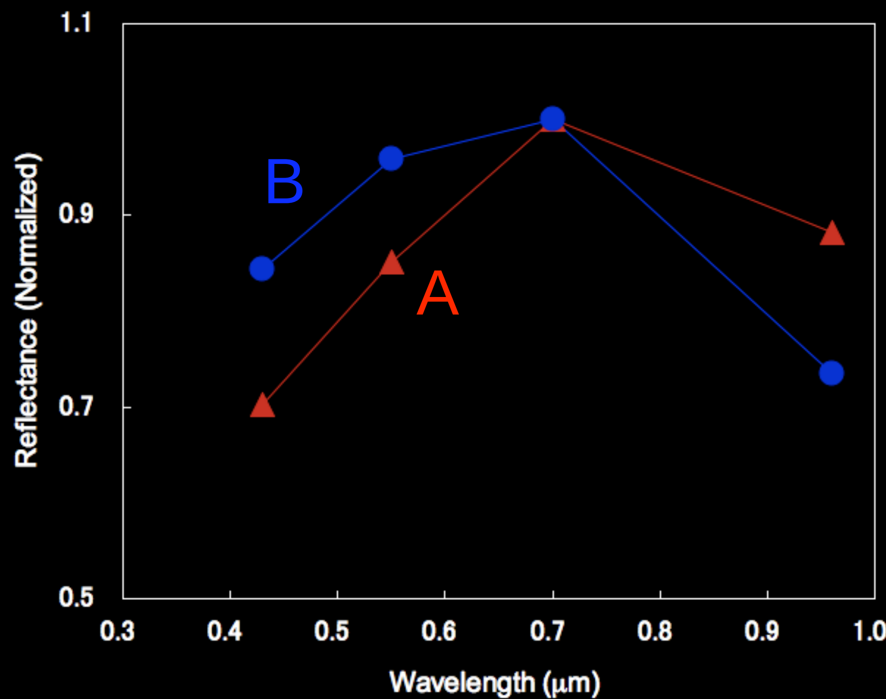
The system efficiency of AMICA seven band filter.

Color Ratio Map

AMICA

Ishiguro et al. *submitted to Icarus*





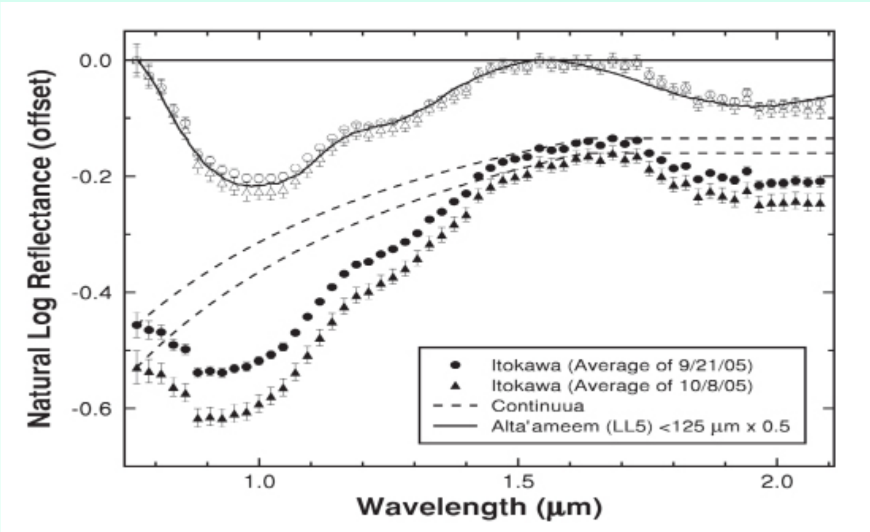
Please contact M. Ishiguro (ishiguro@astro.snu.ac.kr)

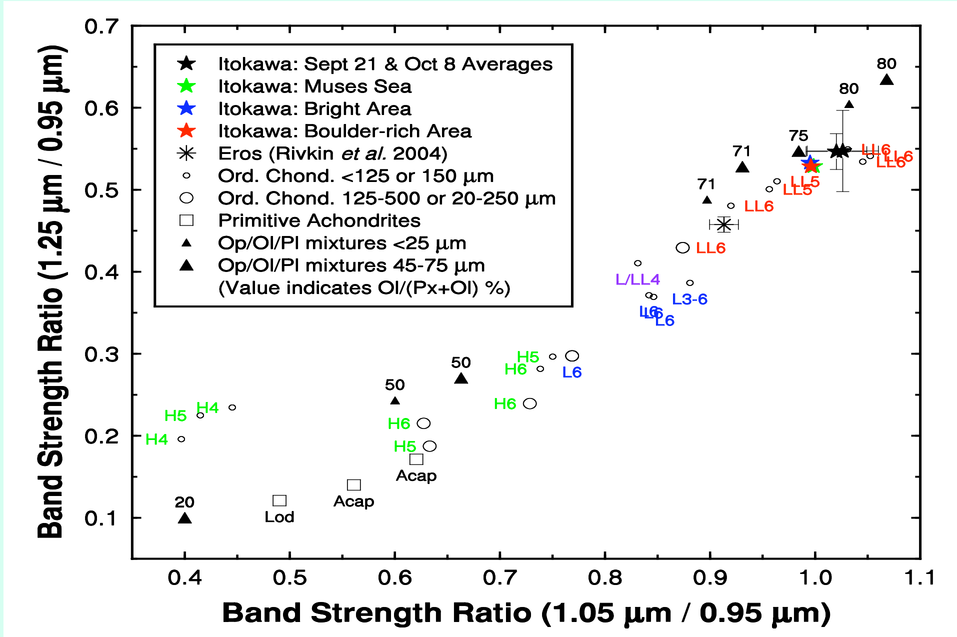
NIRS

NIRS

Observation of Near IR spectrum

M.Abe, et al., *Science* (2006)





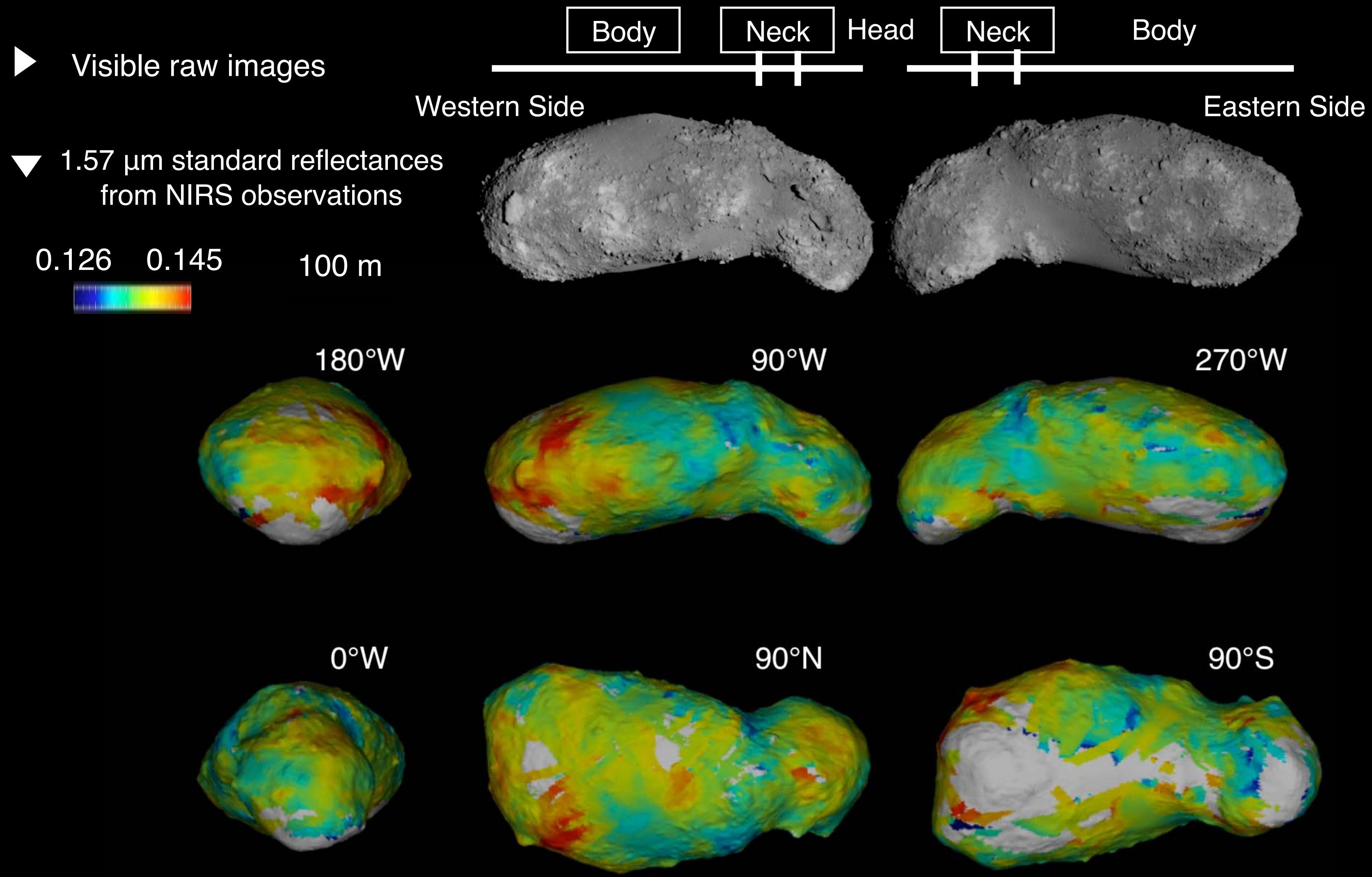
Reflectance spectrum of Itokawa is similar to that of ordinary chondrites.

Itokawa has especially “olivine-rich” surface, compared with other S-type asteroids
Surface materials of Itokawa are similar to LL-chondrites among the known meteorites

LL5-6 chondrites

NIR Albedo Map

K. Kitazato, et al. 2008

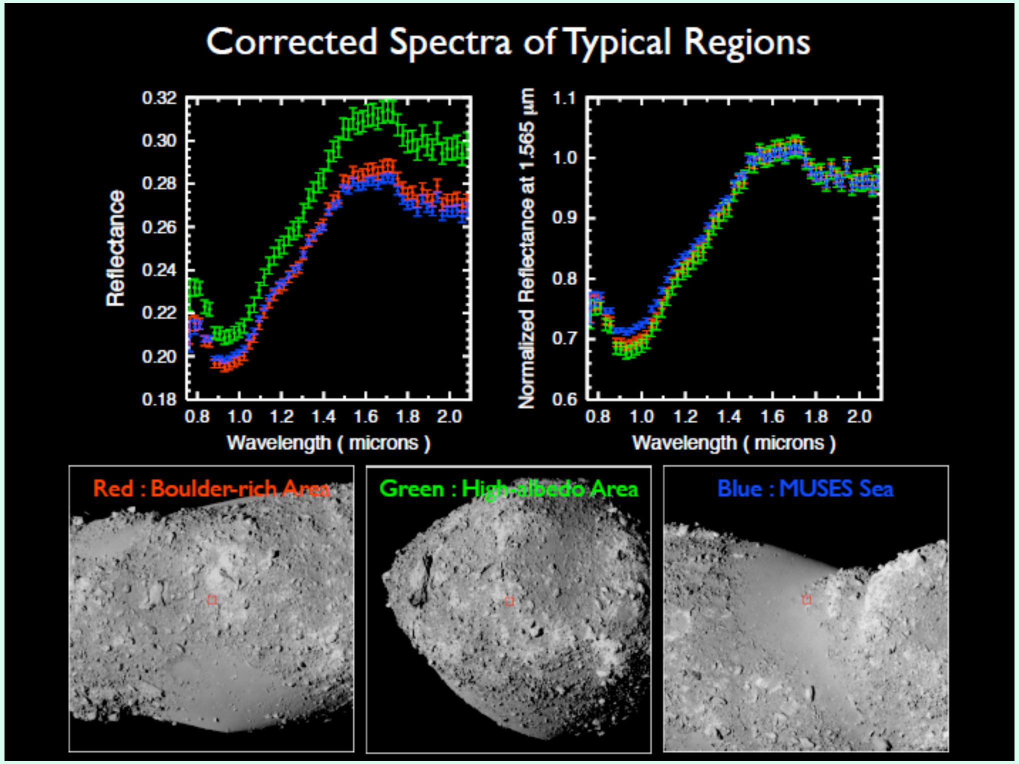


NIRS

Apparent Difference in Spectra May Due to Grain Size and Space Weathering: All Surfaces Indicate Similar Minerals

M.Abe, et al., *Science* (2006)

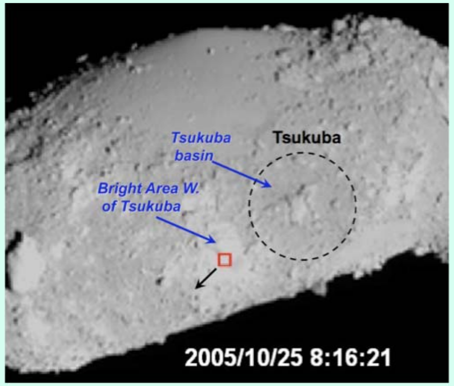
Spectra of three typical regions are different each other in the depth of the 1-micron band. This disagreement is a result of different grain size as well as degrees of space weathering. Otherwise all the spectra suggest basically the same mineralogical materials all over the surface of Itokawa.

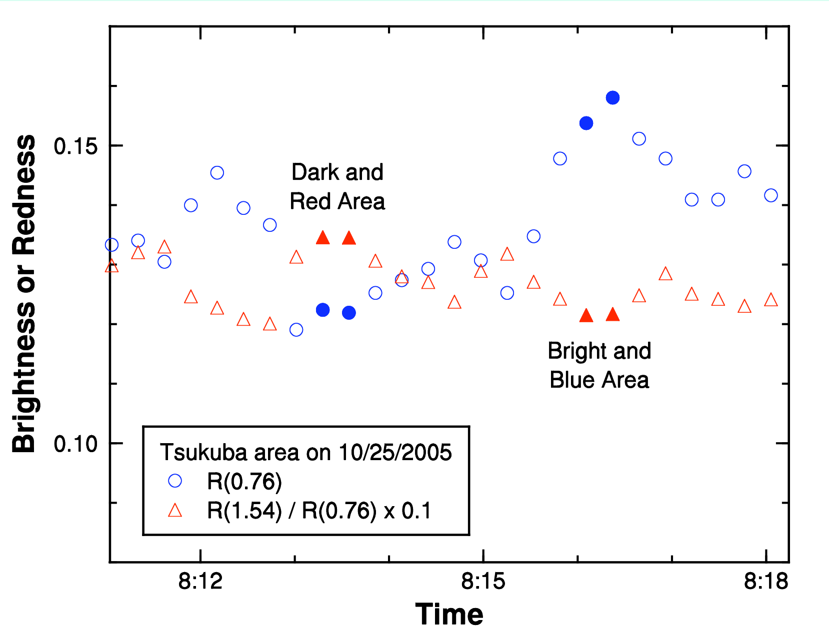


NIRS

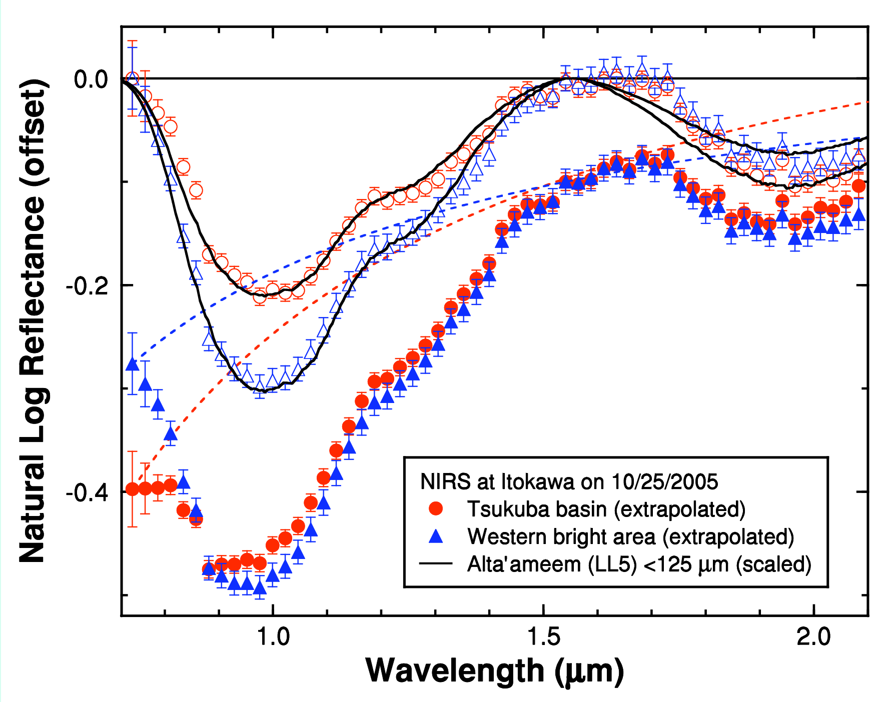
Space Weathering

T.Hiroi, *et al.*, *Nature* (2006)





Tsukuba shows a diversity in both the degree of space weathering (of up to about 0.036% $npFe^0$) and the mean optical path length.



Degree of Space Weathering Relative to Alta'ameem LL5 Chondrite

XRS

Initial Results at Touchdown-1

XRS

Mg-Si ratio is similar to an ordinary chondrite composition

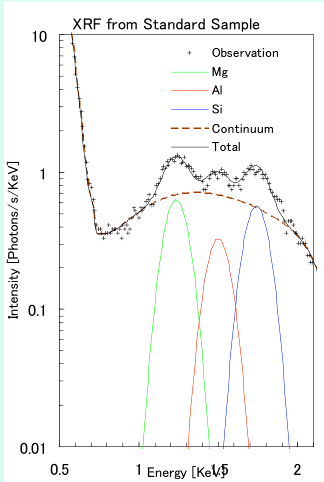
Okada et al., *Science 312*, (2006)

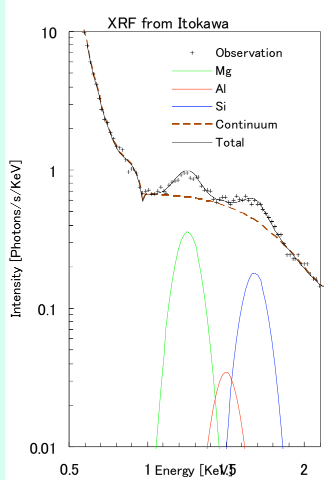
- Surface major elemental composition is like an ordinary chondrite.

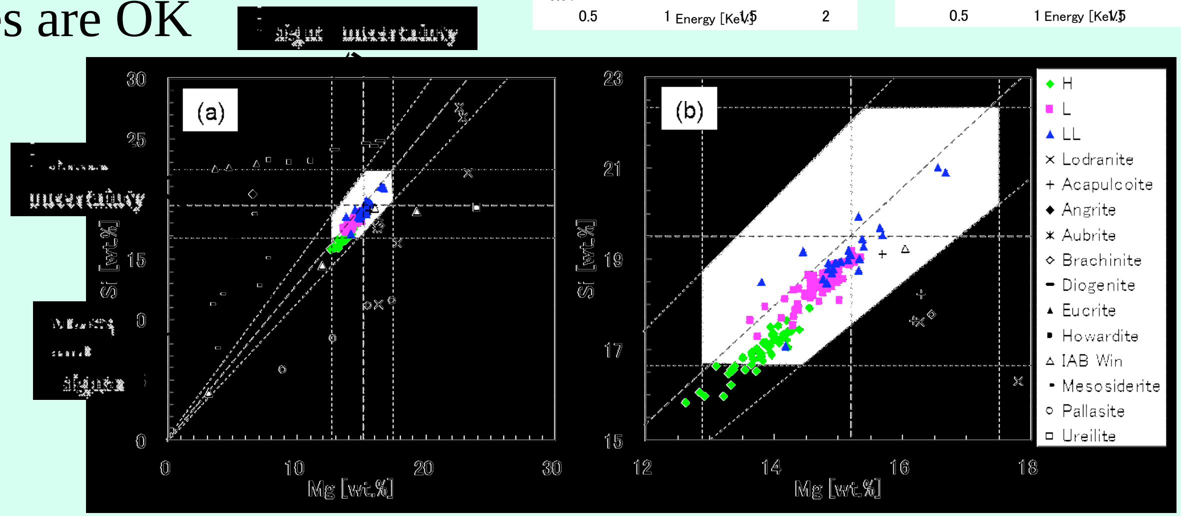
- LL-/L-chondrites are OK

- H-chondrites are OK, but some of them are out of 2-sigma error

- Some primitive achondrites are OK







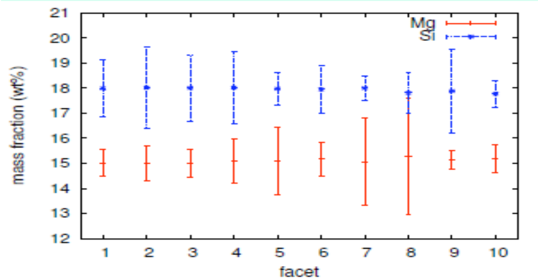
XRS

Regional Results

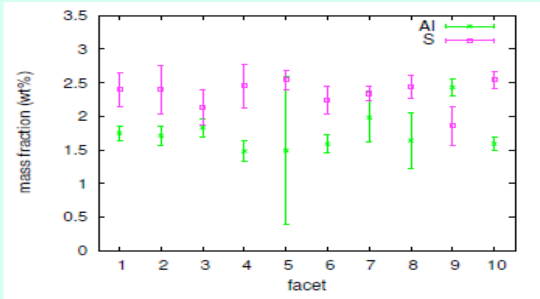
Regionally homogeneous, also chondritic for high-Z elements

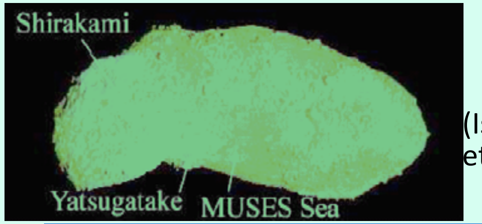
Arai et al. *EPS*, 60, (2008)

Mg, Si

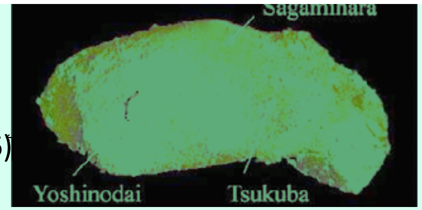


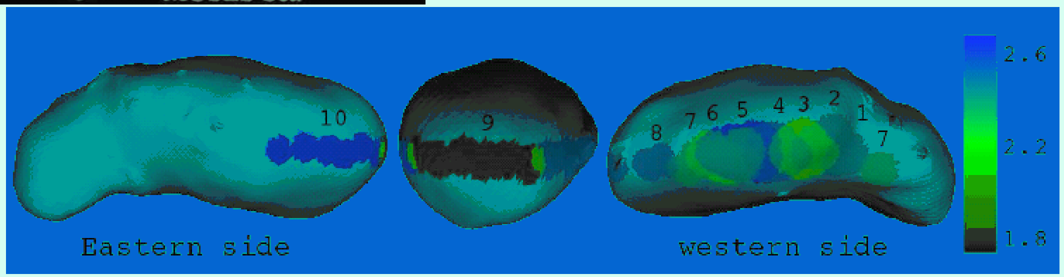
Al, S





(Ishiguro, et al., 2006)





-40KHr data are considered (but mainly with the TD data)
- Footprints are calculated with the SPICE kernels
- Surface irregular features are considered (Aizu Shape Model)

- Globally homogeneous with some exceptions
-Sulfur: almost chondritic or somewhat depleted
- Iron: almost chondritc, LL/L? (not stony irons)

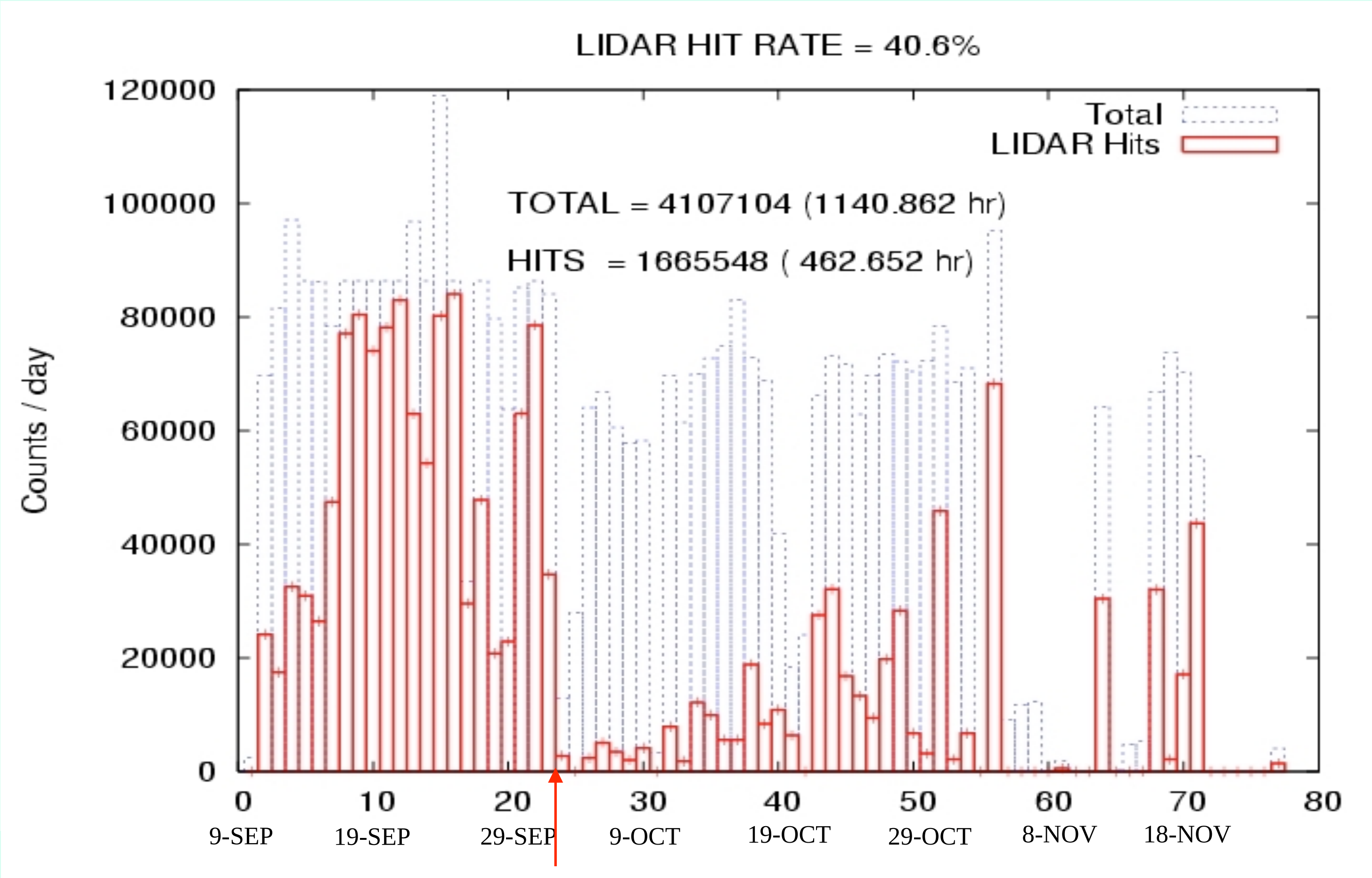
LIDAR

LIDAR

Measurement of LIDAR

S.Abe, et al., *Science* (2006)

LIDAR returns from September 10 to November 25 in 2005

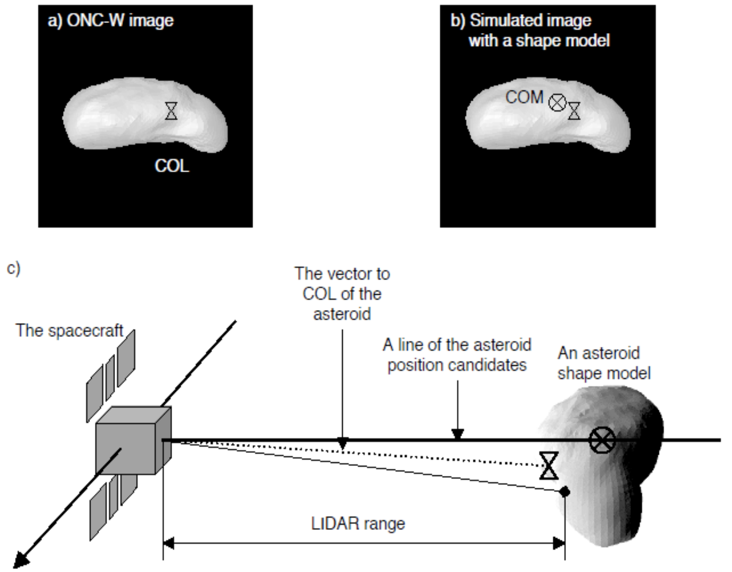


Failures in two of the three reaction wheels(Oct. 2)

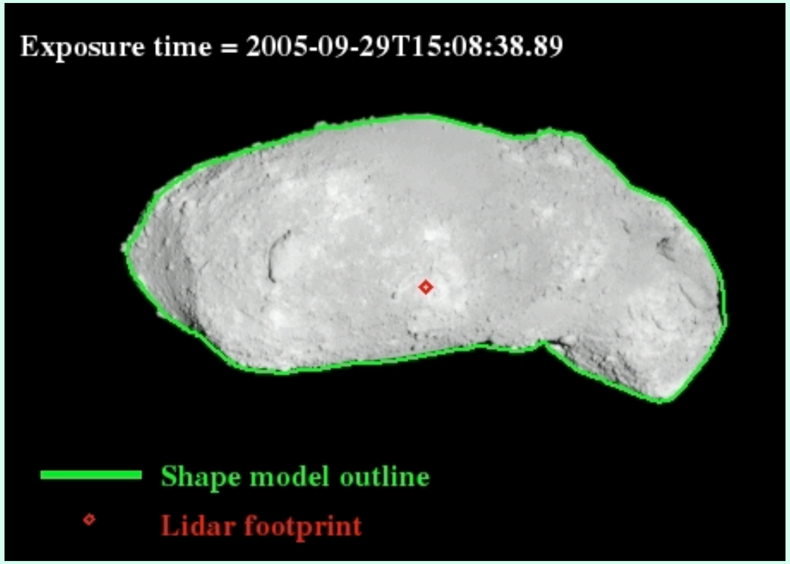
LIDAR

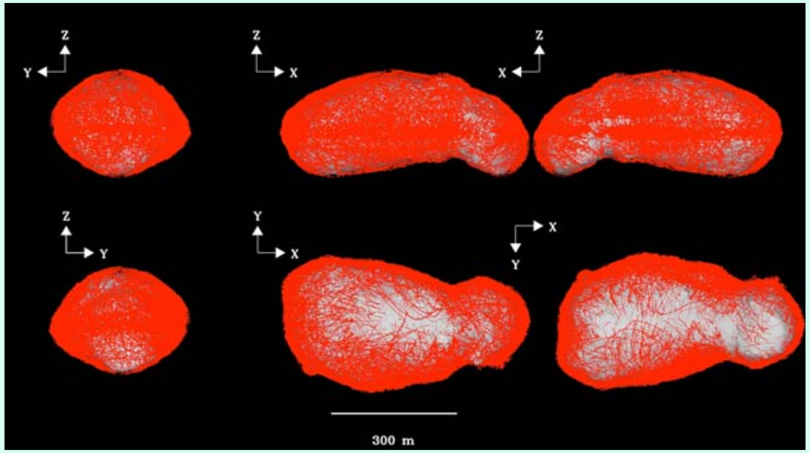
Determination of S/C position by LIDAR, ONC-W and ONC-T

S.Abe, et al., *Science* (2006)



- ✓X-Y location of asteroid center of figure in plane of camera Wide Angle Imager(ONC)
- ✓Range information by LIDAR
- ✓Shape model by Aizu and Gaskell
- ✓Simplified trajectory solution between major thrusts
- ✓Improved pointing between ONC and AMICA(Narrow Angle Camera)



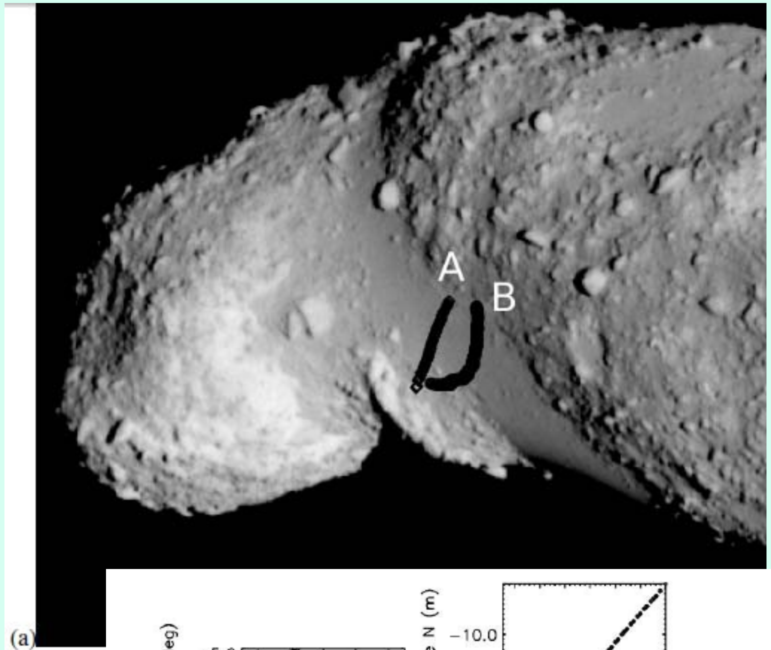


1.3 million good shots ～87% of total

LIDAR

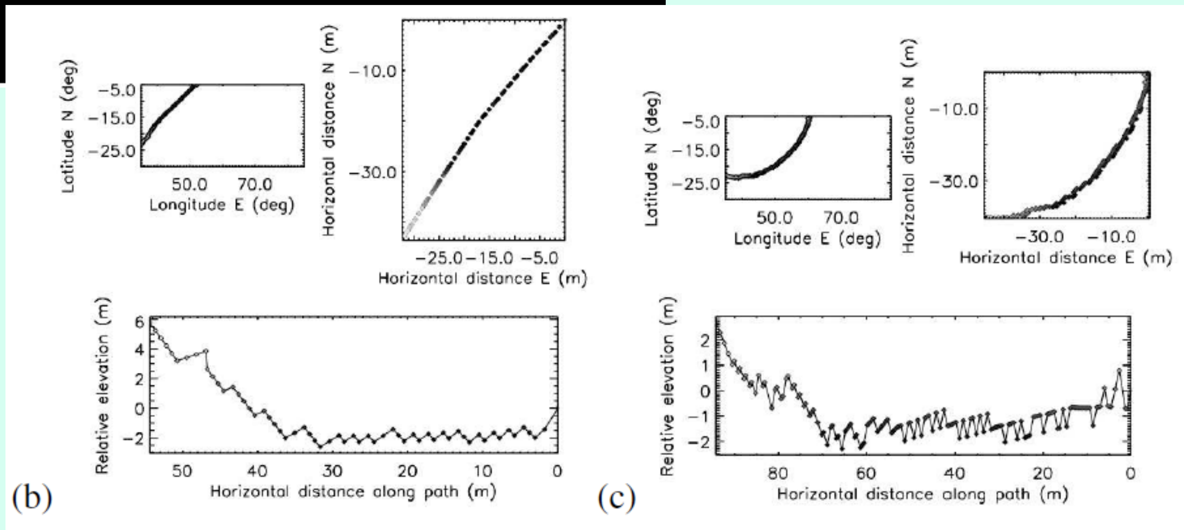
Surface roughness measurements

O.S. Barnouin-Jha et al. (2008)



LIDAR transects across the MUSES-C regio

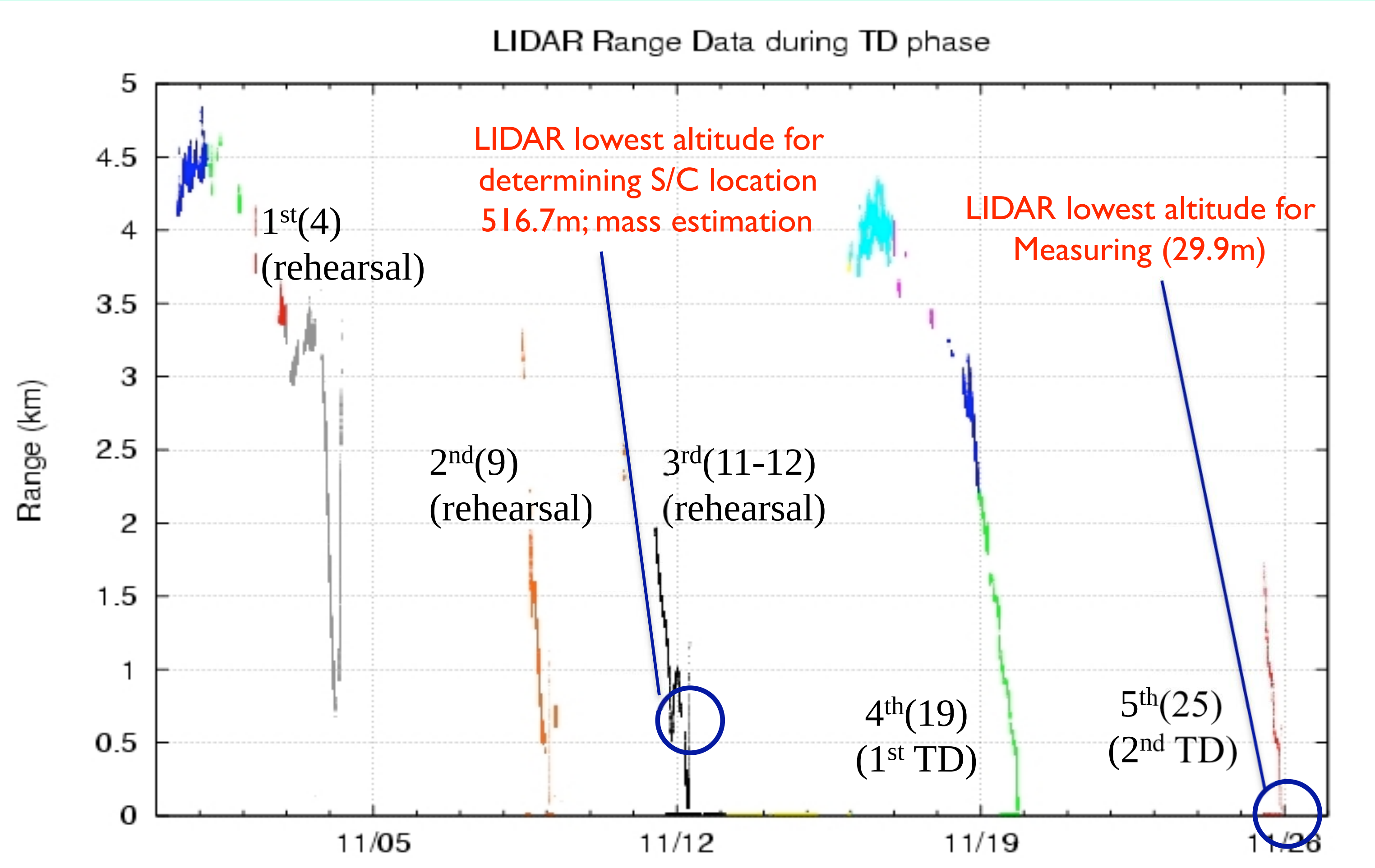
indicating a very smooth surface: (a) AMICA image with the two profiles A and B shown in plots (b) and (c). All the point to point scatter seen in the elevation plots are due to the quantization of the ranges measured by the LIDAR at ±0.5m, implying a very smooth surface, especially compared to all the previous plots where the elevation axes are larger.



LIDAR

LIDAR ranging during the decent phase

S.Abe, et al., *Science* (2006)



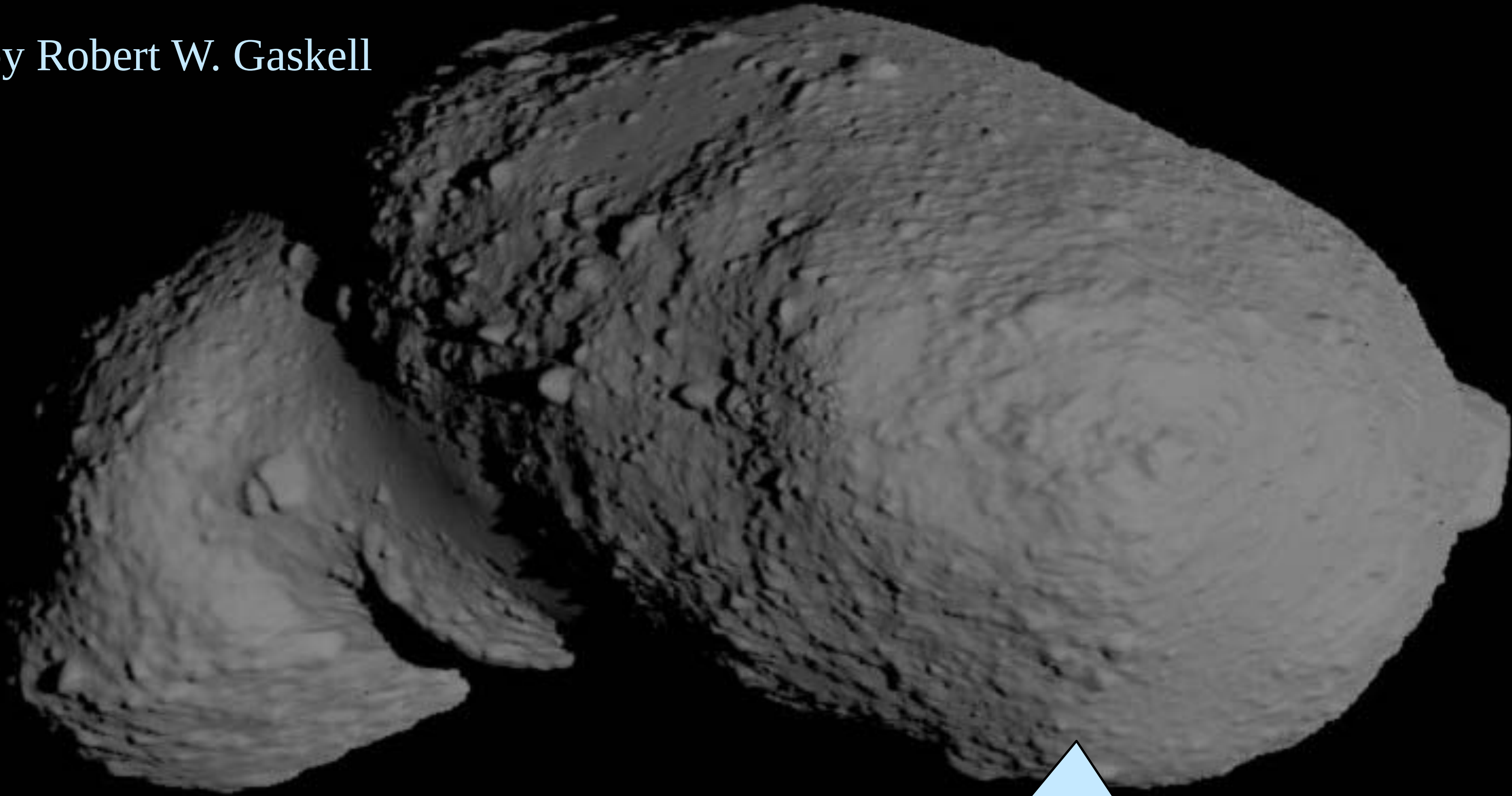
Mass = (3.58 ± 0.18) x 10^{10} kg

Shape Model

Shape Model

Itokawa Global Topography Model

by Robert W. Gaskell



1.57 million vectors
Average spacing 40 cm
RMS postfit residual 14 cm

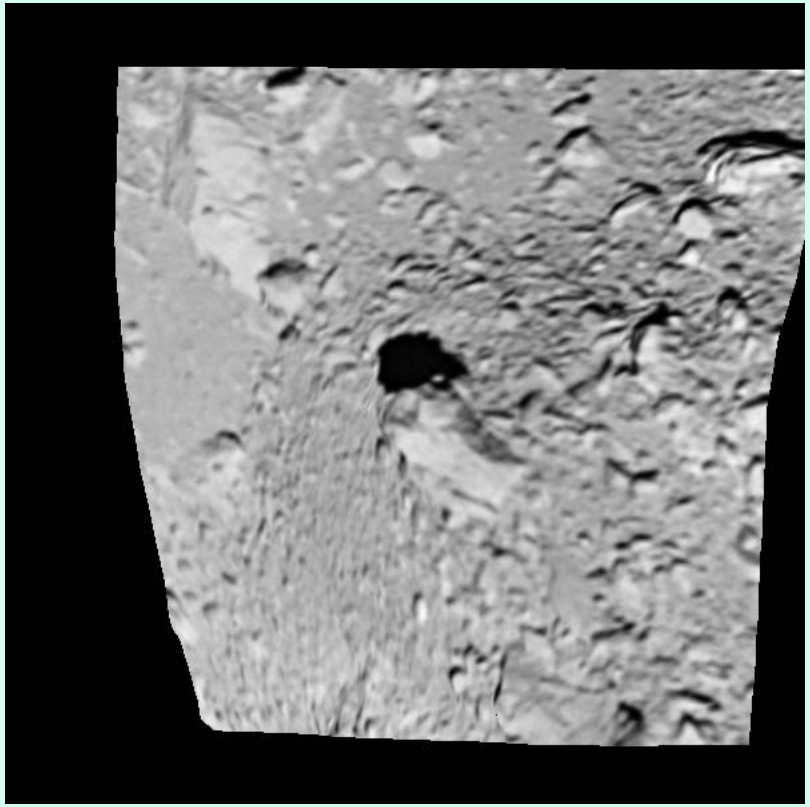
This is a digital model, not real image of Itokwa.

Shape Model

by Robert W. Gaskell

Volume = 0.17732D-01 km^3
Area = 0.40699D+00 km^2
Pole RA = 90.02564º
Pole DEC = -67.02704º

Combining topography and imaging lets us examine the fine structure of the surface in 3D.

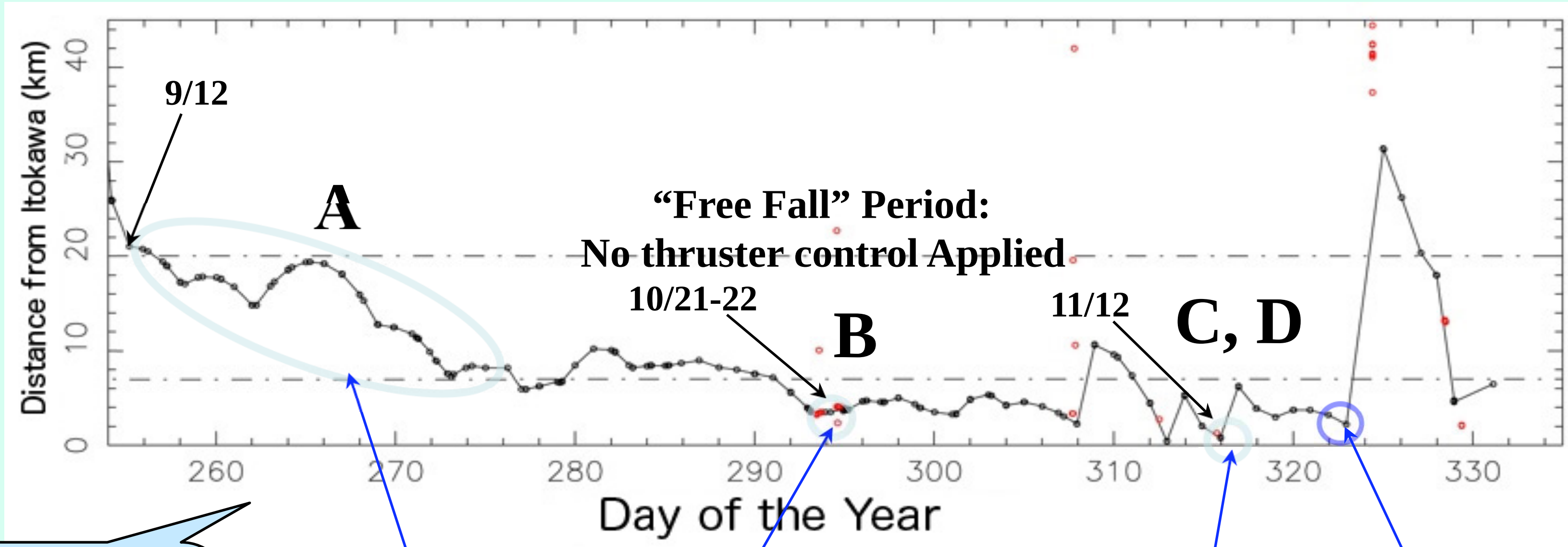


Pencil Boulder

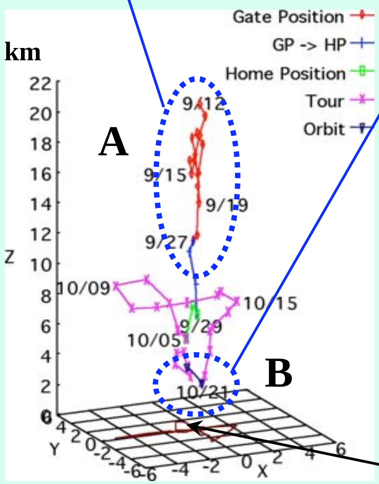
Mass

Mass

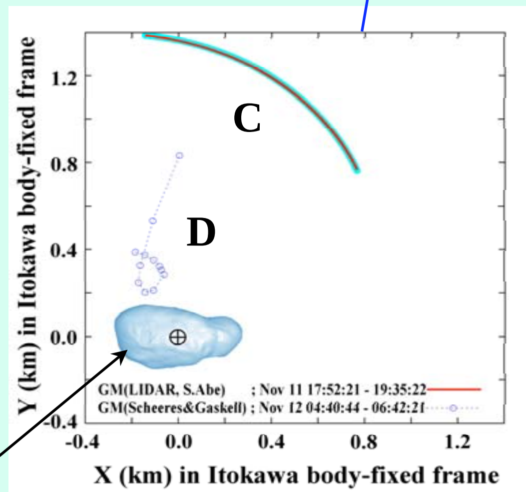
Mass & Density



Mass was determined during the period of A, B, C, and D.



Itokawa



E

1st touch down

Mass

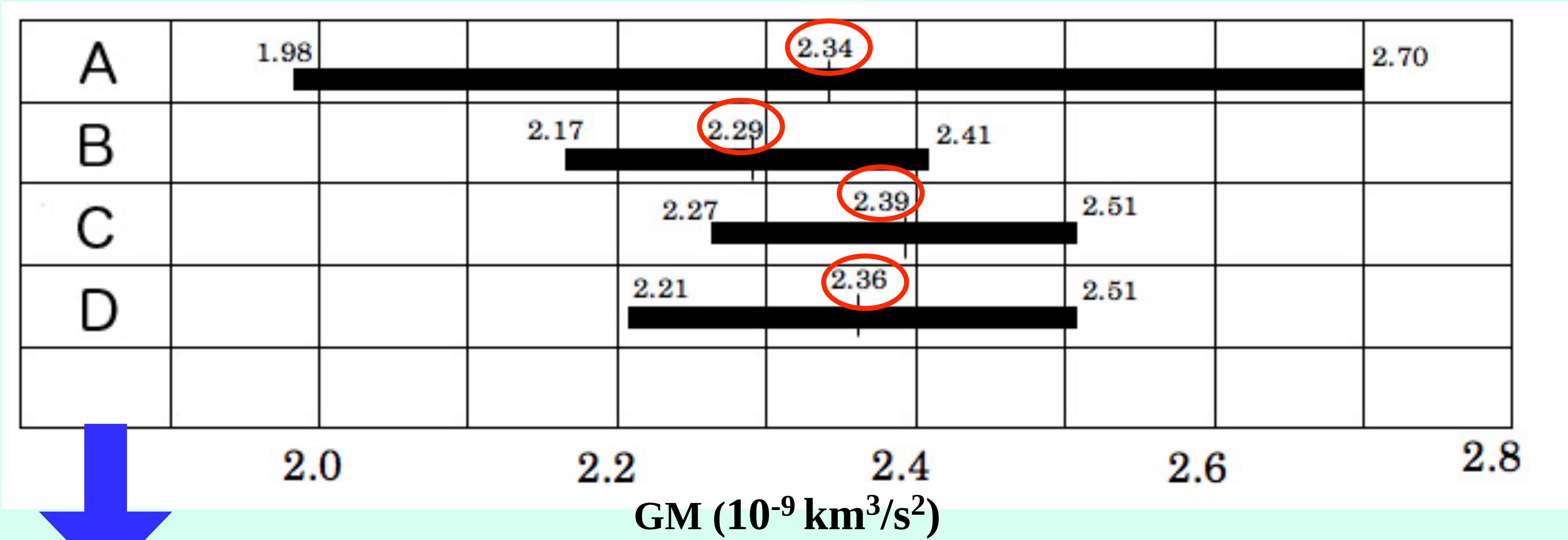
Mass Estimation -1st Results-

Groups	Period / Data type	Distance from Itokawa	Model of Itokawa	**GM** 10^{-9} **km^3/s^2**	Error
A	9/12～10/2 R&RR	20 - 7 km	point mass	**2.34**	15%
B	10/21-22 R&RR, Opt., LIDAR	3 km	point mass	**2.29**	5%
C	11/12 LIDAR, Opt.	1427 - 825 m	polyhedron	**2.39**	5%
D	11/12 Opt., LIDAR	800 - 100 m	polyhedron	**2.36**	6%
E	11/19 LRF	20 - 10 m	-	-	-

Mass

Mass and Bulk Density of Itokawa

Estimated GM in each period (GM=Gravity Constant x Mass)



GM：(2.34± 0.07) x 10^{-9} km^3/s^2

Mass：(3.51 ± 0.105) x 10^{10} kg

Volume = (1.84 ± 0.092) x 10^7 m^3

Bulk Density：1.9 ± 0.13 g/cm^3

Macro-porosity = 40%

Ordinary chondrite

Density ~ 3.2 g/cm^3

Summary

- Since Itokawa is very small, we can approach the unit that builds the planets of the solar system.
- Itokawa may be the rubble pile object.
- The albedo of both visible and near IR varies on the surface of Itokawa, which may be due to the grain size and the space weathering.
- The surface composition is homogeneous.
- The evolution of Itokawa is still interesting problem.

Other Studies

(examples)

Density Inhomogeneity of Itokawa

D.J. Scheeres and R.W Gaskell, *submitted to Icarus/astro-ph*

Itokawa YORP predictions

- YORP computations predict that a spin rate deceleration for Itokawa should have been detected at its last apparition
- It wasn't… why? (Shape model, Total mass, Pole and rotation rate are well known)
- Density inhomogeneities affect the YORP effect ?
- The current non-detection of YORP provides constraints on the possible density inhomogeneity of Itokawa

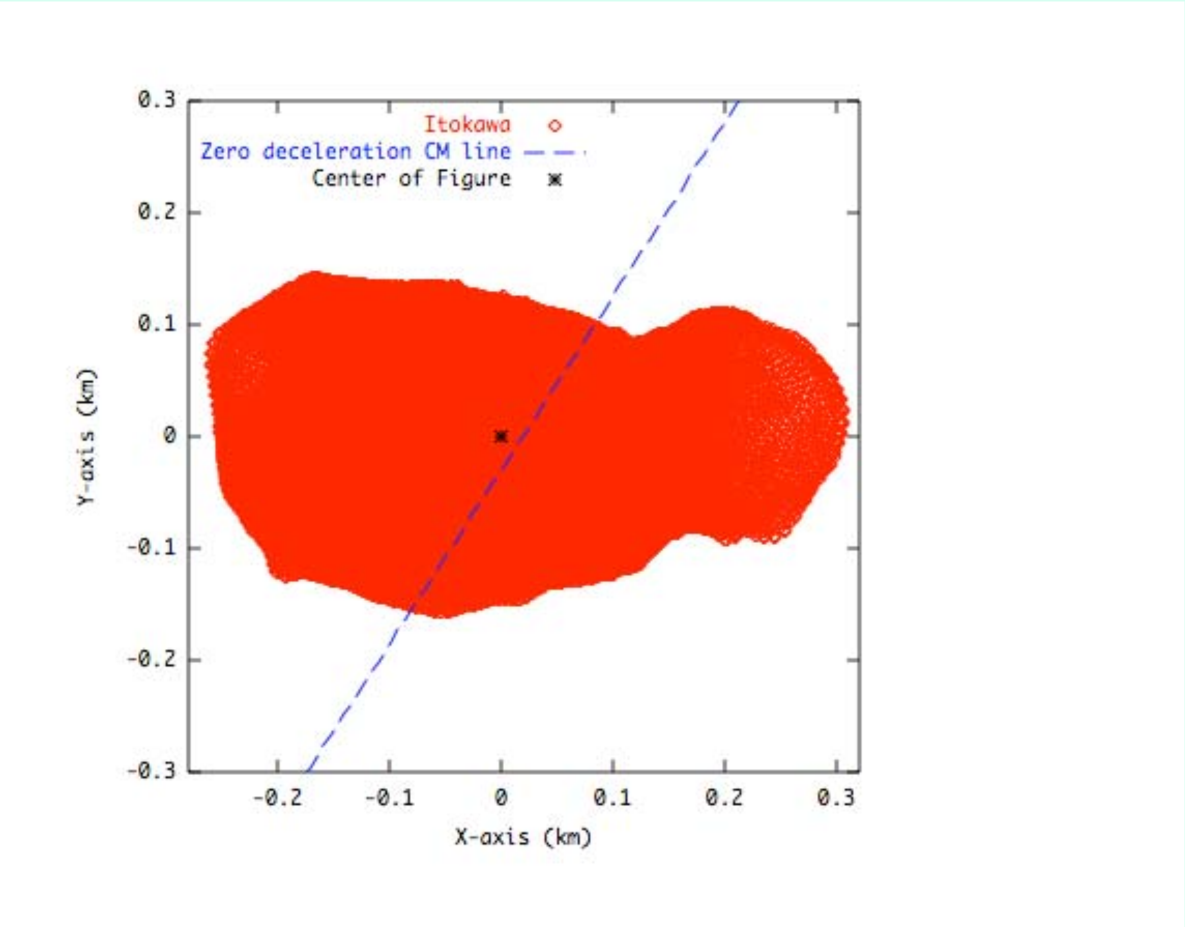
Main effect is to shift the center of mass from the center of Figure :

A minimum shift in center of mass on the order of 15 meters towards the neck/head region can null out the YORP rate of change.

- The Neck region being filled with finer material with same grain density ?
- The Head having a larger density ?

Zero YORP CM lines

D.J. Scheeres and R.W Gaskell, *submitted to Icarus/astro-ph*



Itokawa CM shift direction

D.J. Scheeres and R.W Gaskell, *submitted to Icarus/astro-ph*

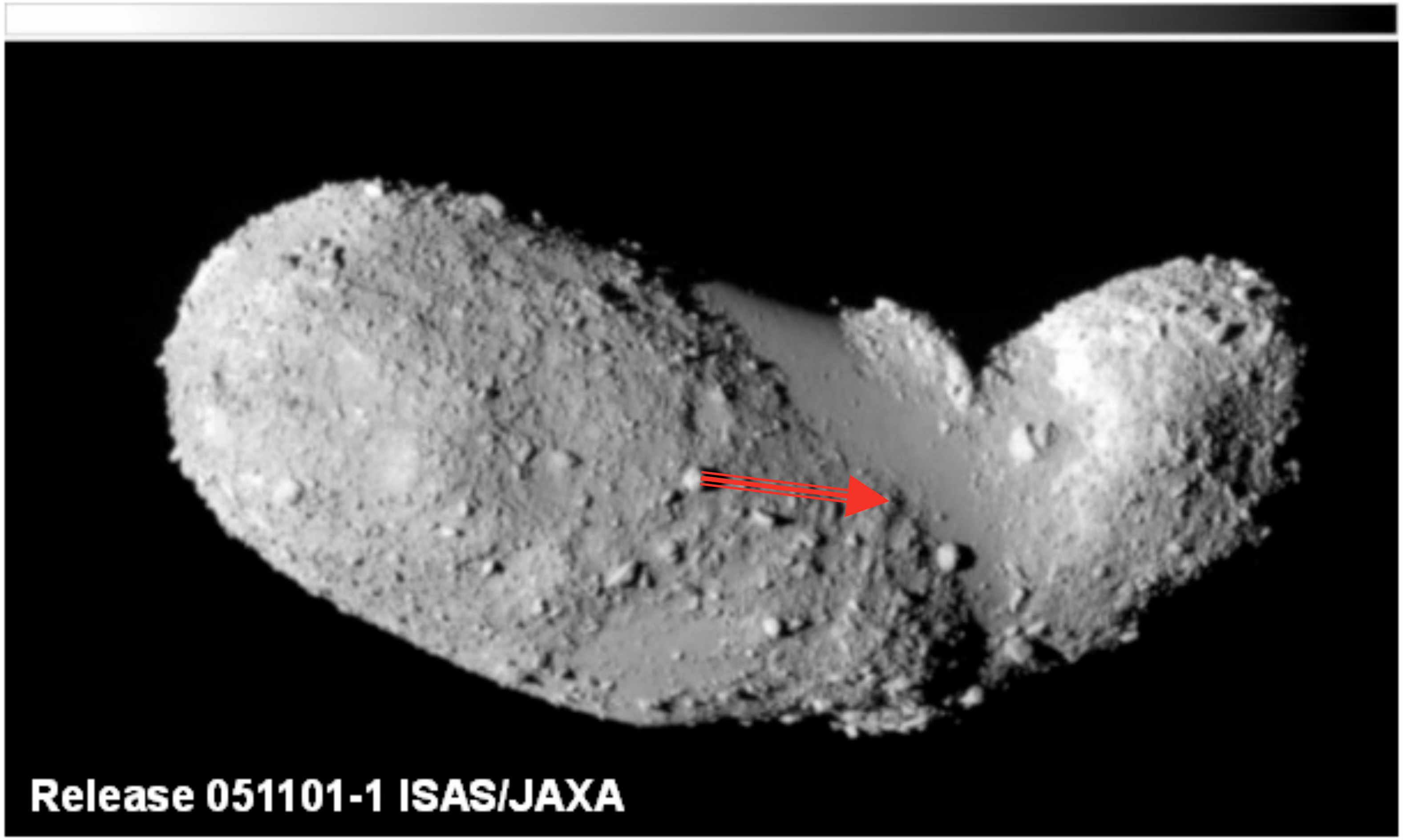


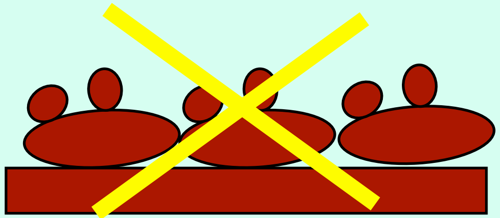
図3 イトカワの +90 度面

Global-scale particle migrations

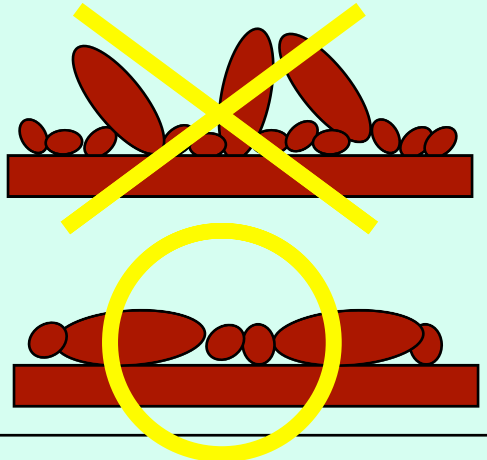
Miyamoto et al. *Science* 2007

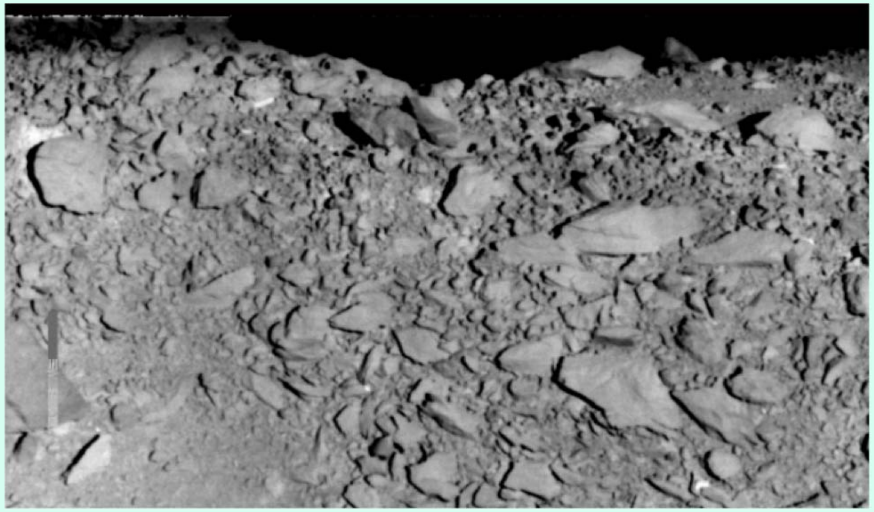
Two important characteristics:

1. None of the smaller gravels are isolated on top of boulders



2. The position and orientation of ravels are stable against local gravity

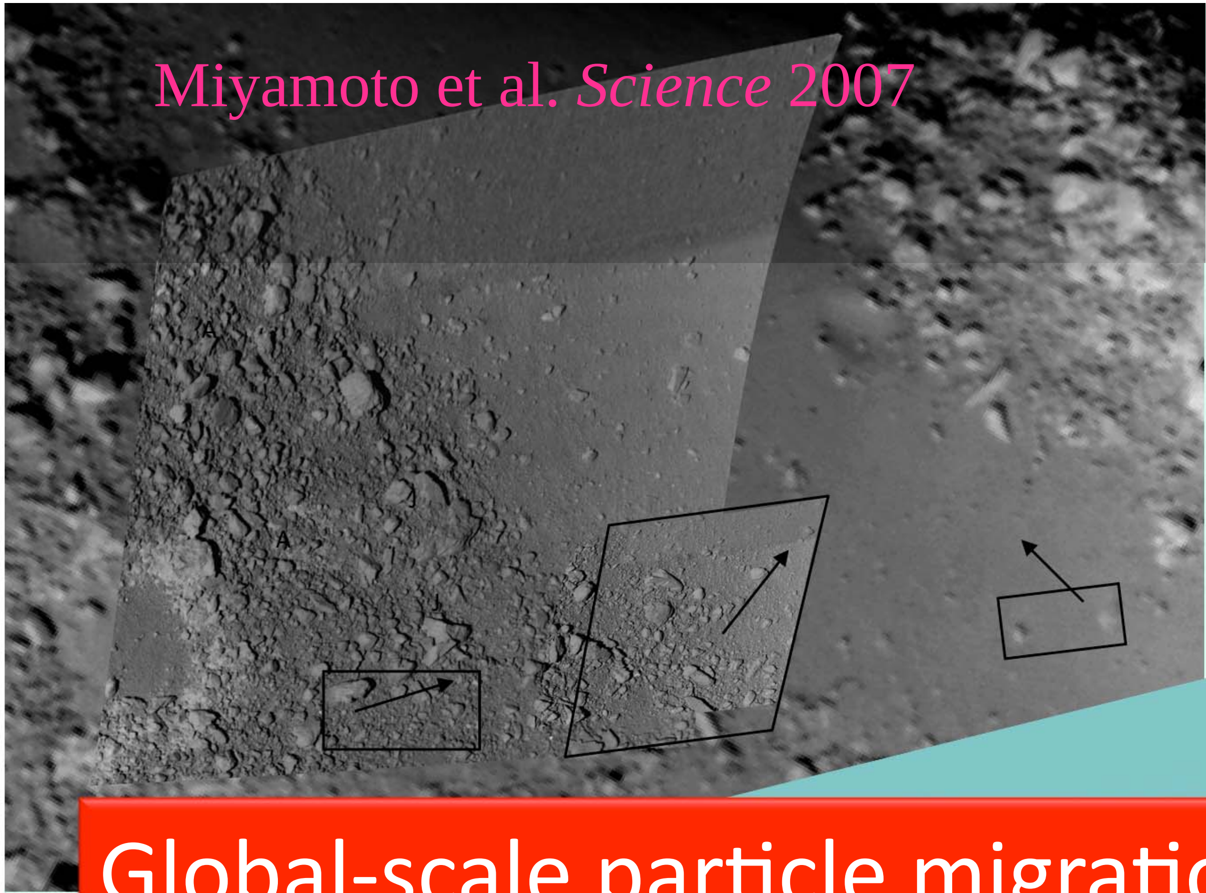




"Gravels on Itokawa were reallocated after deposition"

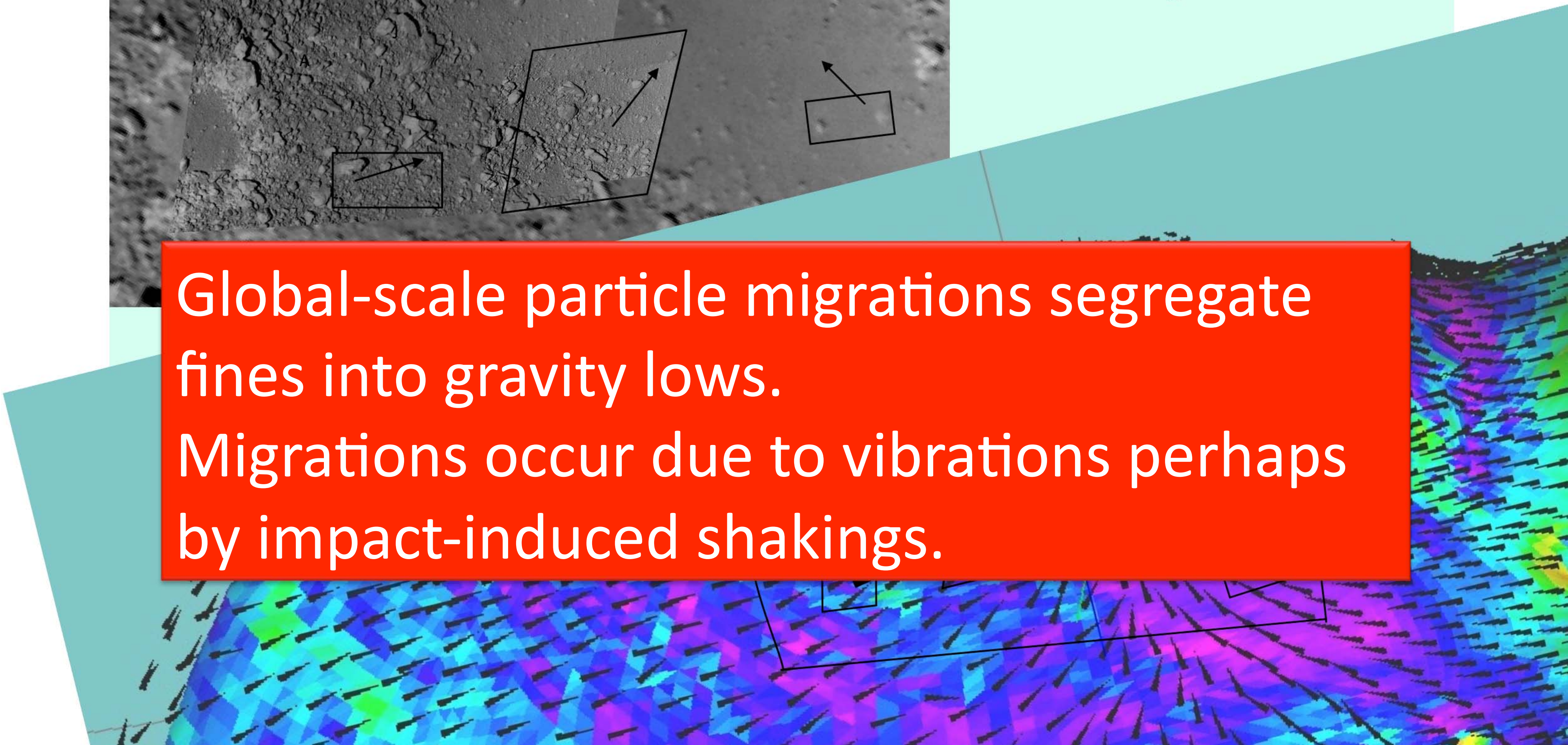
↓

The surface has been subject to *global vibrations*



Critical morphological evidences of gravel migrations

- Imbrications
- Hampered fines
- Jig-saw fit structures
- Boulder alignments



Global-scale particle migrations segregate fines into gravity lows.
Migrations occur due to vibrations perhaps by impact-induced shakings.

Why this process found only on Itokawa?

Miyamoto et al. *Science* 2007

- Distance from the source of seismic energy is generally short at any locations, resulting in effective fluidizations of particles
- A small body keeps the seismic energy, which supports particle fluidizations for a sufficiently long time
- A small body generally has steeper slopes that provides gravitational driving force for particle migrations.